Socio-economic and techno-economic factors associated with establishing a titanium machining industry in South Africa, a qualitative study

by
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Thesis presented in fulfilment of the requirements for the degree of Master of Engineering (Engineering Management) in the Faculty of Engineering at Stellenbosch University

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March 2017

Declaration

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March 2017

Abstract

South Africa is a key producer of titanium raw material, but has very little exposure in downstream industries. The purpose of this study is to investigate what impact a titanium machining industry would have on the country, to show whether the South African government should invest in establishing such an industry.

This was done by investigating South Africa's present position in the titanium market, investigating the countries present socio-economic climate and looking at the techno-economic aspects involved; part of this included defining a concept model for an "ideal" machining cell. To determine interactions between all these factors and show the impact of titanium machining, a soft systems approach was followed focusing mainly on a single machining cell, like the one modelled, and the impact it has on the local community. This impact is negligible on a country scale, but significant for the local economy. The multiplier effect is used to argue that it can be extrapolated to a larger machining industry, and the impact this would have on a broader titanium industry. The goal is for titanium machining to create a market for and drive development of a primary titanium metal industry.

The socio-economic situation in the country provides lots of opportunity for titanium machining to address challenges facing the country, including:

- <u>The country's resource intensive economy</u> – by creating a viable downstream industry, the country can better capitalise on its available titanium resource; fourth largest mineral reserves and second highest mine production.
- <u>The poverty cycle</u> – titanium machining can address unemployment (through job creation) and education (through in-service training) on a small scale. Benefits of breaking the poverty cycle also extend to dependents of employees, affording them a chance for education, proper healthcare and an improved standard of living. The greater potential benefit would be derived from the expansion of upstream industries.

The technical capabilities for titanium machining exist in South Africa as demonstrated by the production of parts for the aerospace sector by private companies; and the research and projects carried out by the CSIR, various universities and industrial partners under the Titanium Centre of Competence. Considering manufacturing in South Africa, the latest Deloitte manufacturing competitiveness index, the country dropped to 27th out of 40 nations. The decline is attributed to growing labour costs without a commensurate increase in productivity, small domestic market, energy crisis, and lack of available infrastructure among others.

Government needs to create an environment in which the sector can thrive, and to focus on long term issues and greater collaboration with labour and business.

In future, gearing a titanium industry towards the industrial sector needs consideration as this provides a much larger market than aerospace and medical sectors, where most research to date has focused. It is also the most significant sector in China, one of the country's strategic trade partners. The soft systems model along with the "ideal" machining cell will need to be refined, quantified and rigorously tested with an industrial partner.

Opsomming

Suid Afrika is ‘n groot produsent van titanium rou materiaal, maar het baie min blootstelling in die verdere verwerkings industrieë. Die doel van die studie is om ondersoek in te stel na die impak wat titanium masjinering industrie sal hê op die land, en te bepaal of die Suid Afrikaanse regering moet belê in die vestiging van so ‘n industrie.

Die studie ondersoek Suid Afrika se huidige posisie in die titanium mark, die huidige sosio-ekonomiese klimaat en kyk ook na die tekno-ekonomiese aspekte wat betrokke is. ‘n Deel van die studie het ingesluit die definiëring van ‘n konsep model vir ‘n “ideale” masjinering sel. Om die wisselwerking tussen al die faktore te bepaal en die impak van titanium masjinering te toon, is ‘n sagte stelsel benadering gevolg waar daar gefokus is op ‘n enkele sel, soos voorgestel in die model, asook die impak wat dit sal hê op die plaaslike gemeenskap. Die impak is minimaal as gekyk word na die hele land se ekonomie, maar het ‘n groot impak op die plaaslike vlak. Die vermenigvuldigings effek is gebruik om die argument te toets op die effek wat dit sal hê op die breër titanium industrie. Die einddoel is dat titanium masjinering ‘n mark sal ontwikkel vir ‘n primêre titanium metaal industrie.

Dis sosio-ekonomiese situasie in die land skep baie geleenthede vir titanium masjinering om huidige uitdagings aan te spreek, insluitende:

- Die land se hulpbron intensiewe ekonomie: deur die ontwikkeling van ‘n lewensvatbare titanium industrie, kan daar beter gebruik gemaak word van die beskikbare titanium hulpbronne, die vierde grootse mineraal reserwes en tweede hoogste myn produksie.
- Die armoede siklus: titanium masjinering kan werkloosheid aanspreek (deur ontwikkeling van werksgeleenthede) en opleiding (in-diens opleiding) op ‘n kleiner skaal, voordele om die armoede siklus te verbreek word uitgebrei na die afhanklikes van werknemers, waar hulle beter opvoeding, gesondheidsorg en ‘n hoër standaard van lewe kan bekostig. Die groter voordeel gaan kom uit die uitbreiding van die verwante industrieë.

Die tegniese vermoëns van titanium masjinering bestaan reeds in Suid Afrika soos bewys in die produksie van die parte vir die lugvaartbedryf deur privaat maatskappye, en die navorsing en projekte wat deur die WNNR**,** verskeie universiteite en industriële vennote onder die Titanium Centre of Competance gedoen is. Die redenasie om vervaardiging in Suid Afrika te oorweeg, spruit uit die laaste Deloitte vervaardigings indeks waar Suid Afrika gedaal het tot 27ste uit 40 lande. Die daling word toegeskryf aan die groeiende arbeidskoste sonder dat daar ‘n noemenswaardige toename in produktiwiteit is, klein huishoudelike mark, energie krisis, en gebrek aan beskikbare infrastruktuur, onder andere. Die regering moet ‘n omgewing skep

waar die sektor kan groei en fokus op die langtermyn probleme asook groter samewerking tussen die arbeidsmag en besigheid.

Vir die toekoms is dit belangrik om oorweging te skenk aan die ontwikkeling van die titanium industrie aangesien dit ‘n groter mark kan bedien as net die lugvaartbedryf en mediese sektore, waar die meeste van die ontwikkeling op gefokus was. Dit is ook een van die belangrikste sektore in China, een van die land se strategiese handelsvennote. Die sagte stelsel model saam met die ideale masjinering sel kan getoets en verfyn word saam met ‘n industriële vennoot en ook gekwantifiseer word.

Acknowledgements

I would like to acknowledge my supervisors Mr Konrad von Leipzig and Prof. Dimitri Dimitrov for their support and encouragement, and for standing by and vouching for me throughout.

I would like to thank my friends and family for all their love and support throughout this process, and pushing me when I lost hope.

I would like to thank my fellow students Bruce Beecroft and Graziano Marcantonio for all the good times, and the bad, through both undergraduate and post graduate studies.

Lastly, I would like to thank my girlfriend, Kristi Smith, without whom I would ever have finished. She stood by me through thick and thin and picked me up when I thought I couldn’t do it

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1. Introduction

South Africa finds itself in a strong position in the titanium mineral sector in both reserves and production. This position however does not translate to downstream industry as most of South Africa's titanium raw material is exported and titanium mill and semi-finished products are imported for use in SME titanium machining operations. Moving forward there is a desire to improve the country's capabilities in value adding industries in the titanium supply chain to better exploit the supply of raw materials.

1.1 Overview of Research

This thesis takes a qualitative look at whether there is merit in investing in establishing downstream capabilities, specifically a titanium machining industry in South Africa. The belief is that establishing a machining industry will serve as a catalyst for broader development of capabilities in the titanium supply chain and help to address some of the economic challenges facing South Africa.

1.1.1 Problem statement

South Africa is key producer of titanium product, it has one of the biggest reserves of titanium raw material and is one of the world's largest producers of titanium slag. However, the country has very little exposure in downstream industries, where most of the value adding processes in the titanium supply chain are found. One downstream industry the country has limited activity in, is titanium machining – a specialised process that is both complex and expensive. As titanium machining is a finishing process it is one of the industries on the titanium supply chain where the most value is added, yielding ten-fold, hundred-fold and even thousand-fold gains in value depending on the final application of the finished product. South Africa is a net exporter of titanium, exporting most of its mine product in the form of titanium slag, and importing limited amounts of mill products for machining. The feasibility of investing in and establishing downstream capabilities, especially a titanium machining industry, needs to be investigated for South Africa to better capitalise on its wealth of raw material.

1.1.2 Objectives

As stated previously, this thesis will investigate whether there is merit in investing in the establishment of a titanium machining industry. As part of this investigation the following questions will need to be addressed.

1. Should the South African Government invest in titanium machining?
2. Why should or shouldn't it invest?
3. What is the way forward?

Government has already invested heavily in the titanium industry and the point of departure is to determine whether to continue investing, particularly in titanium machining. The objectives are focused on answering the above questions and determining whether investment is justified, and if it is why and what is the way forward; conversely, if investment isn't justified, the why and the way forward also need to be determined. The objectives of this thesis are listed below.

1. Investigate the merit of investment in establishing a titanium machining industry
2. To define South Africa's position in the global titanium value chain,
3. To define a model for an "ideal" titanium machining cell,
4. To model the potential impact of titanium machining on South Africa.

1.1.3 Approach

To answer the questions and achieve the identified objectives, three distinct areas are looked at:

- economic and strategic considerations,
- socio-economic aspects,
- and techno economic aspects.

This study starts by exploring economic and strategic considerations of the titanium landscape. South Africa's position on the value chain is defined, highlighting its strength in terms of raw material supply and mine production, but lack of downstream capabilities. This is significant as the greatest gains in value occur downstream on the value chain. It is not only important to understand the country's position and potential on the value chain but also what markets exist for output. The aerospace industry is one of the most significant and well known markets for titanium products and it is here that most titanium machining research in South Africa is focused around. However, it is beneficial to explore other application areas as well to expand the potential market.

Understanding the titanium landscape and South Africa's position in this landscape is not sufficient to provide meaningful feedback; the country's unique socio-economic situation is explored to determine what challenges the country is facing and what the key focus areas are. The challenges identified by the National Planning Commission (NPC) are explored in detail along with key problem areas identified by the Boston Consulting Group (BCG). Performance indicators identified by the Department of Planning, Monitoring and Evaluation are looked at as potential measures by which to gauge the success of establishing a titanium machining industry. Finally, the cost of living for poor households in South Africa is briefly looked at, as this will be significant in modelling the impact of titanium machining.

Where the afore mentioned points deal with the broad picture of the titanium industry and South Africa's socio economic situation, to achieve the objectives of this study it is important to also look at the techno-economic aspects and titanium machining itself. The Industrial Policy Action Plan and Deloitte's Manufacturing Competitiveness survey are looked at to gain an understanding of the manufacturing landscape in South Africa. The Titanium Centre of Competence, the driving force behind titanium related research and advancement in South Africa is briefly looked at. Finally, the process chain for titanium machining is explored and a concept model for an "ideal" machining cell is developed. The "ideal" machining cell is not meant as a definitive rubric for establishing a titanium machining operation but rather a model of the inputs, outputs and processes of a titanium machining cell that can serve as a guide of what needs to be considered to establish one. South Africa is already involved in titanium machining not only on a research and development level but also a commercial level albeit on a limited scale.

By exploring the titanium landscape, South Africa's landscape and the titanium machining process – this study aims to investigate whether titanium machining is worthy of further research and investment. To achieve this, the socio-economic and techno-economic factors are used to develop a soft systems model detailing the interactions between the factors and titanium machining. The soft systems model is developed around the "ideal" machining cell and its impact on employees, their dependents and the local community. This can be extrapolated to make assumptions of the potential impact of a full industry.

South Africa is facing many challenges in the present day such as social, economic, political and environmental challenges. However South Africa also finds itself in a strong position in the titanium value chain as a supplier of raw materials; the onus needs to be placed on utilising this position to develop downstream capabilities as a developing industry can play a role in addressing the country's challenges. Titanium machining is a highly specialised industry, and only one link in the value chain and its direct impact on the economy cannot be expected to be ground breaking; however, the impact at a community level can be significant and the potential knock on impact on the titanium industry needs to be considered.

1.2 Background of titanium metal

This section takes a brief look at the history and properties of titanium metal to show why it is considered a "space age metal."

1.2.1 History

Titanium was discovered in 1790 by British clergyman and amateur geologist, William Gregor. Gregor discovered what he called manaccite when he produced a white metallic oxide from ilmenite, from black magnetic sand found in Manaccan in Cornwall, England. Independently, German chemist, Martin Heinrich Klaproth isolated the same oxide from a sample of Hungarian rutile in 1795. Klaproth named the element titanium after the Titans in Greek mythology, but his efforts to isolate the metal itself were unsuccessful.

1.2.2 Material properties

Titanium is a strong, lustrous silver-white metal with a low density that is especially ductile in an oxygen free environment. Its basic properties are summarised in Tables 1 and 2 below. Table 2 also compares the properties of commercially pure (CP) titanium to other common metals as found in Roskill (2013).

Table 1: Basic properties of titanium (Bentor, 1996)

Name	Titanium
Symbol	Ti
Atomic number	22
Atomic weight	47.88 amu
Density at 20 °C (293.15 K)	4.54 g/cm^3
Melting point	1660 °C (1933.15 K)
Boiling point	3287 °C (3560.15 K)
Classification	Transition metal
Crystal Structure	Hexagonal

Table 2: Comparing properties of CP titanium with other metals (Roskill, 2013)

Metal	**Ti**	**Al**	**Cu**	**Fe**	**Mg**
Melting point (°C)	1660	660	1084	1535	650
Density (kg/cm^3)	4.51	2.70	8.94	7.86	1.74
Thermal conductivity (at 20 °C, W/m.K)	17	239	385	71	147
Thermal expansion coefficient (0 - 100 °C, $10^{-6}K^{-1}$)	7.6	24.0	16.4	11.9	25.7
Electrical resistivity (at 20 °, nΩm)	482	26.8	17.2	97.1	44
Reduction energy (kWhr/kg)	23.1	14.3	…	6.6	18.1

Titanium's key qualities are:

- Low density
- Superior strength-to-weight ratio compared to other structural metals
- Extremely high resistance to corrosion in a variety of environments

The benefit of titanium's low density goes hand in hand with its superior strength-to-weight ratio. The same material strength can be achieved for a fraction of the weight, making it the perfect material for various applications, particularly in the aerospace sector.

Aruvian (2011) compared the strength to weight ratios of commercially pure titanium and two alloys to 4130 steel, 316 stainless steel and aluminium 6061. As the figure given in Aruvian (2011) is in imperial units and only credited with a vague source, (Holt, Mindlin, and Ho, 1997) and (Boyer et al., 1994) were used to find a best match among commonly used structural metals. The strength-to-weight ratios of these and a few additional grades of titanium were calculated based on ultimate tensile strength, results shown in Figure 1.

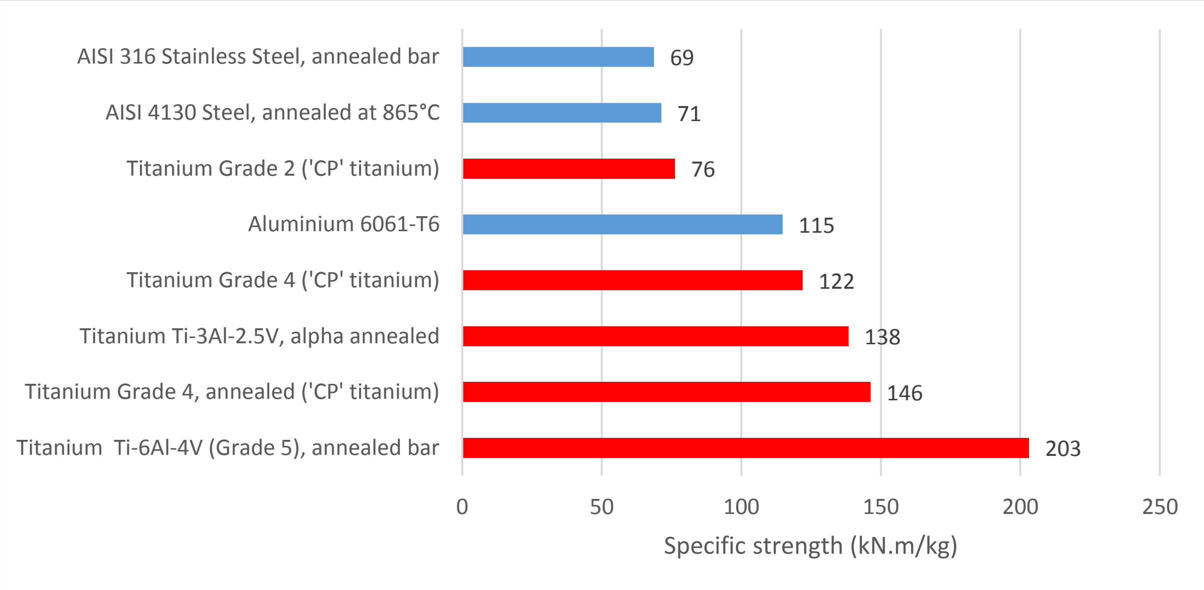


Figure 1: Strength to weight ratios of various metals (adapted from Aruvian, 2012)

As can be seen from Figure 1, CP titanium matches and outperform common low-grade steel alloys. Taking Grade 4 CP titanium as an example Aruvian (2011) points out that: it has an ultimate tensile strength of 550 MPa (unannealed), equal to that of 4130 and 316 steel but is around 45% lighter; it is 60% more dense than aluminium 6061 (one of the most commonly used aluminium alloys) but is more than twice as strong (annealed). The most common titanium alloy, titanium 6-4 (also shown in Figure 1) has the highest strength to weight ratio of any structural metal, approximately 1.8 times that of aluminium 6061 and more than 3 times that of 316 stainless steel (Roskill, 2013).

The other key quality of titanium is its corrosion resistance in various environments including seawater, body fluids (making it ideal for use in biomedical applications) and natural juices. This is due to the spontaneous formation of an oxide film I the presence of any oxygen (Roskill, 2013). If this layer is damaged, it immediately repairs itself. The film starts off as a thin coating

1-2 nm thick but continues to grow, reaching a thickness of 25 nm in four years (Aruvian, 2011). This film makes titanium almost as resistant as platinum, protecting the titanium against various dilute and organic acids, chlorine gas, chloride solutions, various salts and other compounds.

Other notable properties of titanium, divided by Roskill (2013) into those with a positive commercial significance and those that are negative, are listed below. The properties that have a positive commercial significance allow titanium to be used in a wide range of applications that will be discussed in the next chapter.

Properties with positive commercial significance:

- Low modulus of elasticity (55% that of steel)
- Can be processed as a powder metal
- Non-toxic and compatible with human bone and tissue
- Favourable heat transfer and electricity conduction properties, with no thick surface oxide build up
- Can be forged using most standard techniques
- Can be cast, formed and machined – despite being classed as a difficult to machine material (needs to be machined using intuitive pathing and cooling techniques, and at lower speeds than other metals, such as steel)
- Joinable by fusion welding, adhesives and brazing
- Has a unique ability to be effectively coupled with carbon fibre reinforced polymers (CFRP)

Negative properties:

- Difficult to extract due to the strength of its bond with oxygen
- Rapidly corrodes in concentrated acids – including hydrochloric, sulphuric and hydrofluoric acid – as well as hot caustic soda, phosphoric acid, and boiling aluminium chloride
- Corrodes in dry chlorine, as well as ammonia and hydrogen sulphide at temperatures above 150°C
- Its high affinity for common gases such as oxygen, nitrogen, carbon dioxide and hydrogen during melting and in interstitial solid solution makes melting and alloying process costly and maintaining purity difficult.

2. Economic and strategic considerations

This chapter takes a brief look at the economic and strategic factors relevant not only to the titanium machining industry but the entire titanium industry. These include South Africa's standing in the global titanium supply chain – available reserves, production and consumption, looking at both past and present data. The titanium metal market will be looked at to determine which countries are the major producers and consumers of titanium and titanium products. The titanium value chain will be explored, highlighting the potential of downstream activity and various application areas for titanium.

2.1 Titanium value chain

In September 2012, at the Seminar on Additive Manufacturing of Titanium Parts, South Africa's market position in the minerals industry was discussed. This formed part of a presentation on the Titanium Centre of Competence's (TiCoC) commercialisation strategy for titanium focusing on the advancements and goals regarding titanium powder production. Table 3, taken from this presentation highlights South Africa's position.

Table 3: SA Titanium Market Positioning (Damm, 2012)

	South Africa	World	Share
Reserves	220 Mt TiO2	1,300 Mt TiO2	**17%**
Mineral Production	1,090 kt TiO2	5,200 kt TiO2	**21%**
Slag Production	1,090 kt TiO2		
Pigment Production	20 kt TiO2	5 Mt TiO2	**<1%**
Sponge Production	-	88 kt/a Ti	**-**
Ingot Production	-	130 kt/a Ti	**-**
Mill Products	-	70 kt/a Ti	**-**

The country was stated as having the world's second largest reserves of titanium, approximately 17%, and counted as one of the leaders in titanium mineral production, at 21%. The presentation also highlighted the lack of downstream activity in South Africa where titanium ore is mined and exported, primarily in the form of titanium slag. A limited amount of processed sponge and metal products are then imported for use in industries. This practice limits the country's potential for exploiting its favourable position, which was also highlighted in an interview with Dr Willie du Preez (Technical Director of the TiCoC) (Clark, 2012); du Preez pointed out that South Africa has a downstream market for titanium products with players in the aerospace and biomedical markets, and a healthy supply of raw material, but no beneficiation process in-between (Clark, 2012). Sponge, Ingot and Mill product production provide an industrialisation opportunity for the country.

To understand the scale of the shortfall we need to look at the titanium value chain. Titanium occurs naturally bonded to other elements and mainly occurs as minerals. The two most common titanium bearing minerals are rutile and ilmenite, which are mined and processed into titanium tetrachloride ($TiCl_4$). The case of ilmenite, it is first processed into titaniferous slag (titanium slag) or synthetic rutile. The $TiCl_4$ is then processed into and sold as titanium pigment, or by means of the Kroll process it is converted to sponge, mill and finally finished products. A simple breakdown of the value chain, along with approximate market values of titanium (in US Dollars per kg contained titanium) is shown in Figure 2. The value chain is adapted from value chains presented by Aruvian (2011) and Damm (2012), and information derived from Roskill (2013). The market values of titanium in different forms are adapted from figures given by Damm (2012), Roskill (2013) and USGS (2014), and while not exact, they represent a reasonable approximation and indicate the downstream increase in value of titanium. The market value of mill products is strongly dependent on grade, alloy as well as country of origin; the given value is based on aerospace quality material from Europe and the US.

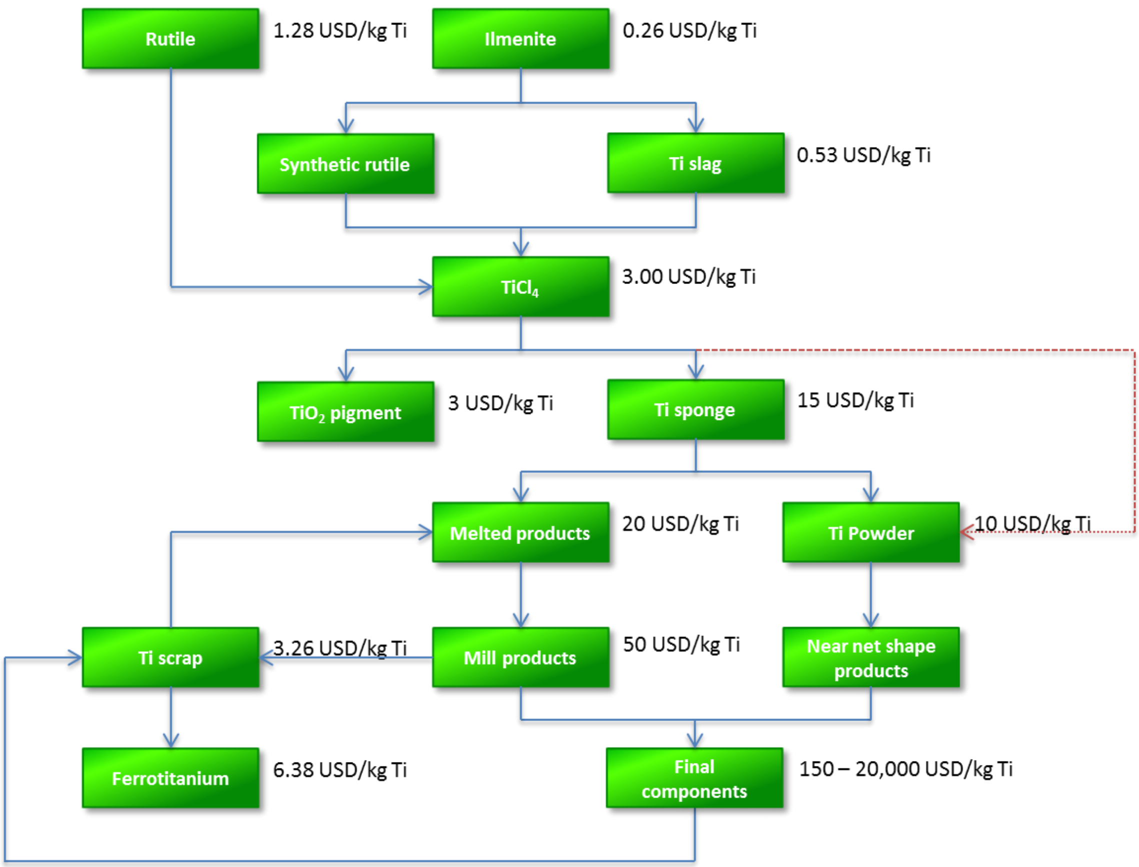


Figure 2: Titanium value chain

As seen in the figure, substantial value is gained by processing titanium. Considering most South African exports are in the form of titanium slag, and companies such as Aerosud and Daliff Precision Engineering import mill products to turn into final components for aircraft manufacturers, this represents massive economical loss for the country, with mill products having 100 times the value of titanium slag. Given South Africa's large natural reserves and mine production, as well as experience in production of final components, it is easy to see why the titanium supply chain presents a great opportunity for industrialisation and the potential to have a positive and significant impact on the economy.

2.2 Titanium Resource

Per Roskill (2013) only about 7% of the content of the mine production of titanium minerals is processed through to metal. Bearing this in mind, resource and production data serve more as an indicator of potential sources of raw material rather than an actual metric for titanium supplies.

Before delving into titanium reserves data, it is important to note a few key points. The most readily available source for information regarding titanium reserves is the United States Geological Survey (USGS) which publishes annual and quarterly reports regarding mineral commodities for the United States and the rest of the world. Important points to note about the USGS reports that influences reserves data:

- Prior to 2005, no data regarding Chinese titanium reserves was published by the USGS
- Until 2009, two separate values regarding titanium reserves were published, one for reserves and one for the reserves base. The USGS defines these as follows:
    - Reserves base: That part of an identified resource (in this case titanium deposits) that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness and depth. It includes parts of the resource that have a reasonable potential for becoming economically available within the planning horizons beyond those that assume proven technology and current economics.
    - Reserves: Only that part of the reserve base that can be economically extracted or produced at the time of determination.

  For the purposes of this report, except for background purposes, only the reserves as defined by the USGS will be considered. It can therefore be assumed that this value can fluctuate from year to year not only due to depletion by mining, but also due to parts of the reserve base becoming or ceasing to be economically available.

- While titanium reserves for most countries are reported separately as ilmenite and rutile, the United States reserves of rutile are included with ilmenite, but as the United States is not a leader in reserves nor mine production this has no effect on conclusions drawn.
- Totals reported are rounded off and therefore may differ to totals appearing in this report.

2.2.1 Reserves

The reserves values highlighted by Damm (2012) in Table 2, are based on reserve base data and include only totals for titanium in the form of ilmenite. It is therefore important to reassess these figures to get a more accurate and therefore more relevant description of South Africa's competitive position. The values used are derived from USGS mineral commodity summaries published in 2009, the last year reserves base data was published. Reserve and reserve base values for South Africa and other leading countries for the year 2009 are presented in Table 4 to provide a richer picture of South Africa's position at the time and to highlight the difference between reserves and reserve base; the values are sums of ilmenite and rutile reserves.

Table 4: Titanium resource by country, 2009 (USGS, 2009)

	Reserve base (kt TiO_2)	% of world total	Reserves (kt TiO_2)	% of world total
Australia	181000	12%	152000	21%
China	350000	24%	200000	27%
India	230000	16%	92400	13%
South Africa	244000	17%	71300	10%
Rest of world	448970	31%	213980	29%

As can be seen in the table less than 50% of the reserve base was economically available in 2009. We also see that when considering only the economically available reserves South Africa's strategic position in the titanium market diminishes significantly, dropping from second with 16% of the world share to fourth with a mere 10% share. Even at this weaker position, South Africa remains one of the world's leading titanium resource suppliers.

The values for titanium reserves of any country are revised annually based on new information supplied by governments or industries. Changes in reported reserves can depend on various factors, for example the discovery of new titanium deposit, advancements in technology or changes in government legislature allowing exploitation of previous unattainable deposits; the reported titanium reserves can also decrease due to overestimates in previous years or changes in the economic situation of specific countries. Figure 3 shows total titanium reserves for the years 2002 through 2014, titanium reserve base as reported by the USGS is also included for reference until its publication was discontinued.

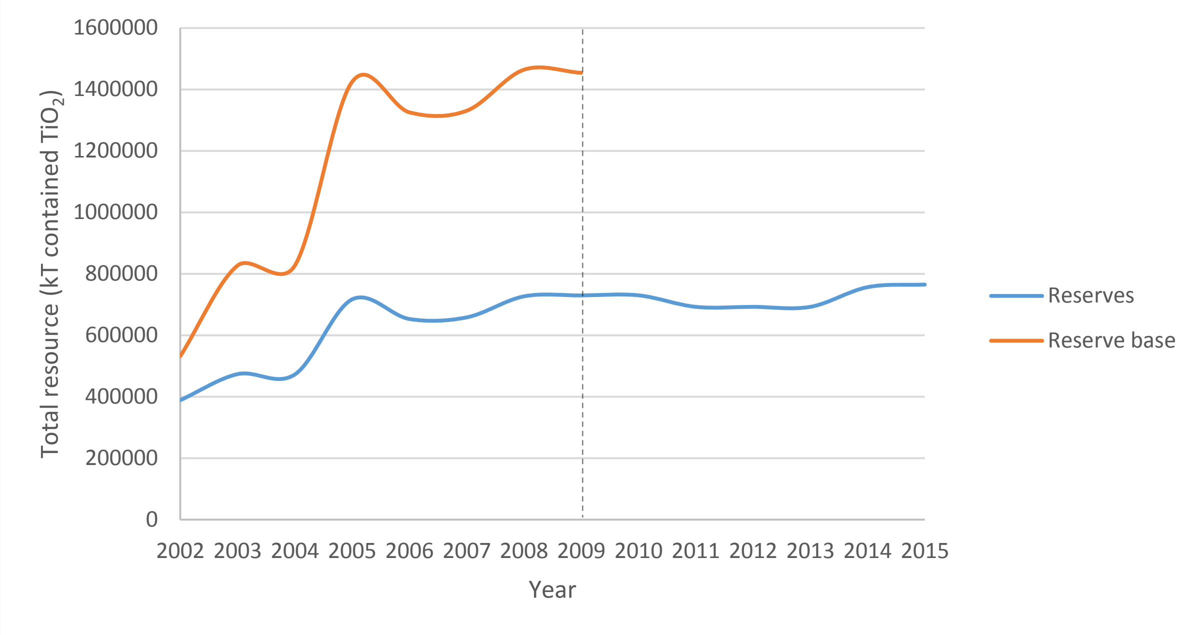


Figure 3: World titanium supply, 2002 - 2015 (USGS, 2002-2015)

As can be seen on the graphs there was significant variation in reported reserves prior to 2008. The initial rise is due to Australia revising and increasing its reported reserves, which it then revised again in 2006 and lowered. The significant increase in 2005 is due to the inclusion of Chinese reserves in the data supplied by the USGS. The slight increase in 2008 is due to an increase in reported reserves in Brazil and other countries. By looking at the disparity between the reserves and reserves base lines we can see that there is significant potential for much larger titanium reserves given favourable technological and economic conditions in future years.

To look at South Africa's position in the titanium market today, we look at the 2014 USGS Mineral Commodity Summary. Table 4 and Figure 4 compare South Africa with other key titanium producing countries. Table 5 compares the major players in the titanium market by comparing ilmenite and rutile reserves separately. South Africa holds the fourth largest reserves of titanium in the form of ilmenite and the second largest reserves of the less common, rutile.

Table 5: Titanium reserves by country, 2015 (USGS, 2015)

	Ilmenite (kt TiO_2)	% of world total	Rutile (kt TiO_2)	% of world total
Australia	170000	24%	28000	60%
China	200000	28%	0	0%
India	85000	12%	7400	16%
South Africa	63000	9%	8300	18%
Rest of world	200500	28%	2900	6%

In Figure 4 we see that South Africa now has the fourth largest, or 9% of the world's total titanium reserves. This is not as strong a market position as was assumed a few years ago, when the TiCoC was established and South Africa embarked on its titanium beneficiation program.

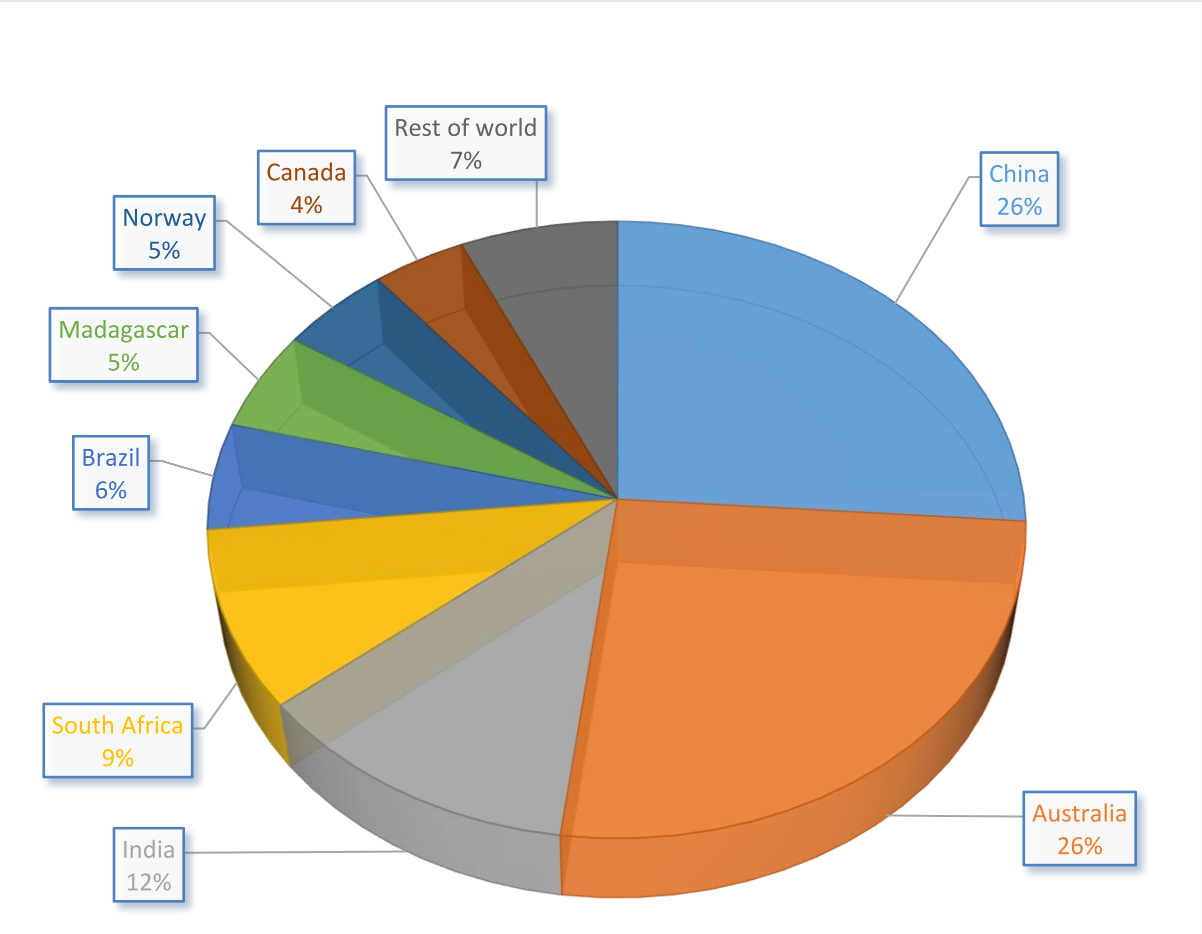


Figure 4: Division of titanium reserves by country, 2015 (USGS, 2015)

2.2.2 Mine Production

As in the previous section, titanium mine production data is derived from reports by the USGS and it is important to note the following that influences production data:

- Prior to 2005, no data regarding Chinese titanium production was published by the USGS
- Mine production in Canada and South Africa is primarily used to produce titanium slag
- While titanium production for most countries is reported separately as ilmenite and rutile production, data for the United States includes rutile production with ilmenite and is rounded to one significant digit to avoid disclosing company proprietary data
- Totals reported are rounded off
- Values for 2014 are estimated and therefore subject to change

As discussed in the previous section and shown in Figure 1, during the presentation for "TiCoC Commercialisation Strategy and Lessons Learnt" in September 2012 (Damm, 2012), South Africa's position in the minerals industry was highlighted, crediting the country with 21% of the world's titanium mine production, most which is used to produce titanium slag. While South Africa's production has remained constantly around the 1000kT contained TiO_2 per annum mark over the past decade, the percentage share of the world's total mine production has been steadily dropping as mining operations in various other countries are ramped up.

Figure 5 shows the mine production of the world's top four titanium resource producers over the decade 2004-2013 (the USGS reports mine production figures with a 2-year delay) and compares them with mine production in the rest of the world. The estimated production for 2014 is also included. We see in the figure that like South Africa, Australia and Canada have remained consistent in their production while China has more than doubled its output. We can also see that the rest of the titanium producing countries have significantly increased production. Thus, world mine production in 2013 totalled over 7400kT contained TiO_2, the highest ever recorded. It is estimated that production remained stable in 2014 on the back of increased output in Australia and Canada. Australia, South Africa, China and Canada together were responsible for approximately 60% of the world's titanium mine production in 2013.

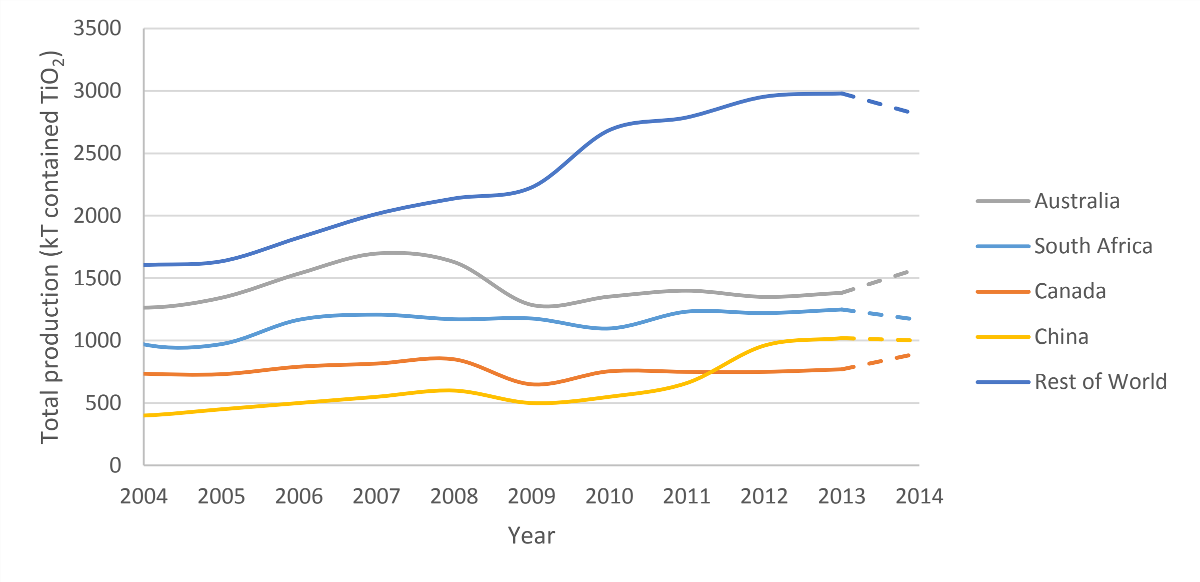


Figure 5: World titanium mine production, 2004 - 2014 (USGS, 2005 - 2015)

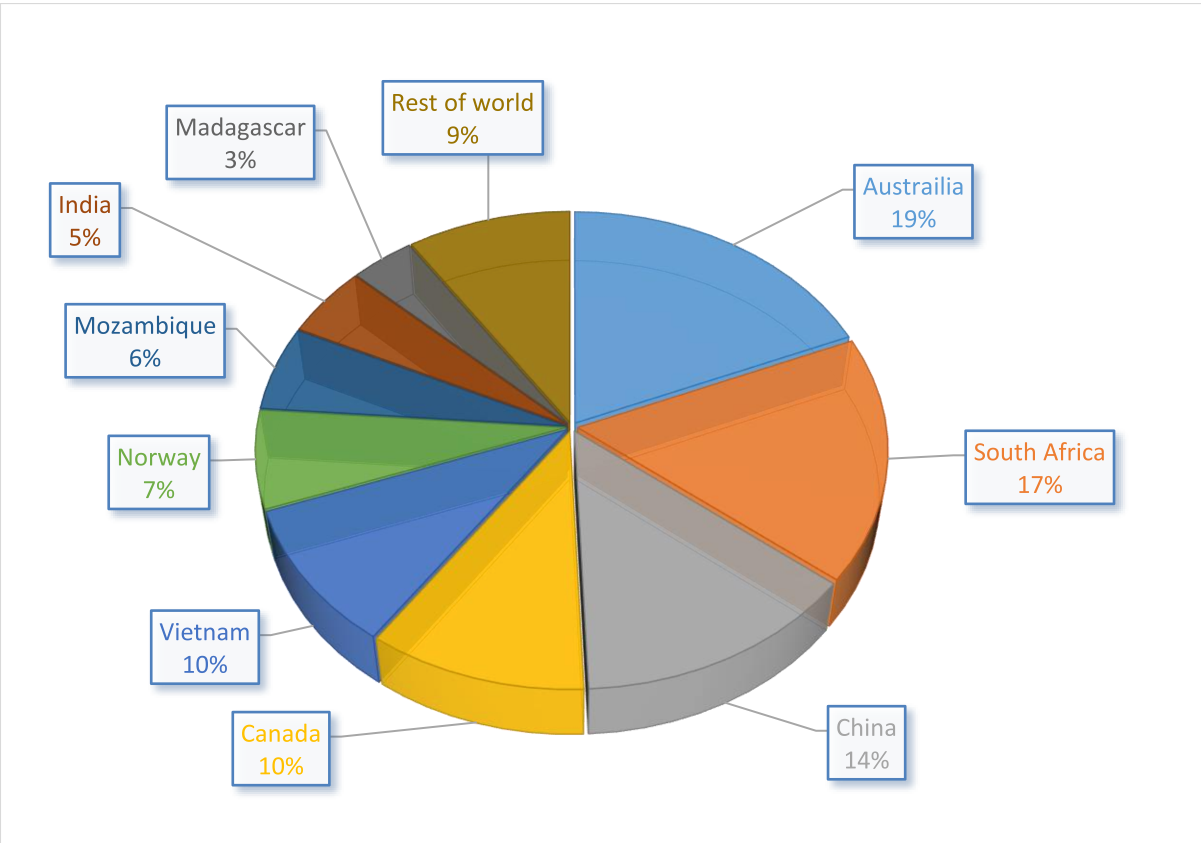
In Table 6 we have a summary of titanium mine production by country over the decade 2004-2013, along with the estimated figures for 2014. As seen in the table countries like Madagascar, Mozambique and Vietnam have set up and/or significantly expanded mining operations in recent years. Vietnam experienced a seven-fold increase in production over the decade, bringing it on par with the world's leading titanium producers. Output in Vietnam is expected to fall back to around the 500 kt mark in 2014 however, which is consistent output experienced from 2010 to 2012. Mozambique and Madagascar came into the decade with little or no recorded mine output but developed projects at Corridor Sands (Mozambique) and Fort Dauphin (Madagascar) and started showing output in 2007 and 2009 respectively, quickly ramping up to become key players in the market. Among the world leaders Australia remains the world's largest titanium producer with production expected to rise above 1500kt in 2014, South African and Chinese production is expected to remain around the 1000kt mark while Canadian production is expected to ramp up to match them.

The breakdown of the world's titanium producers for the year 2013 is given in Figure 6. As was seen previously, South Africa is the world's second largest producer, accounting for 17% of the world's titanium mine output. Per the USGS (2015), South Africa is the main import source of titanium to the United States accounting for 40% of the total US titanium imports.

Table 6: Titanium mine production by country 2004-2014, kt contained TiO_2 (USGS, 2005-2015)

	2004	2007	2010	2013	2014e
United States	300	300	200	200	100
Australia	1264	1697	1352	1383	1580
Brazil	133	130	48	100	70
Canada	735	816	754	770	900
China	400	550	550	1020	1000
India	299	398	564	364	366
Madagascar	0	0	177	272	347
Malaysia	0	0	0	14	14
Mozambique	0	14	411	430	500
Norway	381	377	300	498	400
Sierra Leone	0	79	65	81	120
South Africa	970	1208	1097	1249	1165
Sri Lanka	0	0	34	32	32
Ukraine	274	347	357	200	260
Vietnam	98	254	485	720	500
Other	120	115	44	68	98
Total	4974	6285	6438	7401	7452

Figure 6: Division of titanium mine production by country, 2013 (USGS, 2015)



Per Roskill (2013) and supported by calculations from available data, approximately 90% of the world's mine production of TiO_2 is in the form of ilmenite. The remainder is mainly rutile and a small amount of leucoxene, including anatase. About 45-50% of the production of ilmenite is converted to titanium slag, a third of which occurs in South Africa. Other major producers of slag include Canada and Norway, and slag used in the production of titanium sponge is primarily produced in China and countries from the former Soviet Union. A further 10-15% of ilmenite is converted to synthetic rutile, mostly occurring in Australia, and the rest is used directly in the production of pigments. Most natural rutile is produced in Australia and South Africa. Table 7 breaks down titanium mine production into ilmenite and rutile by country for the major producers from 2010-2013.

Table 7: Ilmenite and rutile mine production by country (USGS, 2012-2015)

Ilmenite	**2010**	**2011**	**2012**	**2013**
Australia	991	960	940	960
Canada	754	750	750	770
China	550	660	960	1020
South Africa	952	1110	1100	1190
Rest of world	2518	2616	2751	2794
Total	5765	6096	6501	6734
Rutile	**2010**	**2011**	**2012**	**2013**
Australia	361	440	410	423
Sierra Leone	65	64	89	81
South Africa	145	122	120	59
Ukraine	57	56	56	50
Rest of world	45	51	57	54
Total	673	733	732	667

2.3 Application and uses of titanium

Titanium is a high strength low density metal that is costly to extract and process through to finished products both encouraging and restricting its use to advanced and high value applications. Roskill (2013) identifies the following applications for titanium metal:

- Components in both engines and airframes for aerospace, both commercial and military
- Plate and tube heat exchangers
- Chemical and petrochemical plant equipment
- Anodes and coating in chlor-alkali processing (production of chlorine and sodium hydroxide)

- Turbine blades and condenser tubes in nuclear and fossil fuel power generation
- Piping and structural applications in offshore oil and gas drilling
- Cathodes and cladding in non-ferrous metallurgy
- Prosthetic components (including for the spinal, hip, knee and dentistry) in the medical field
- Marine structures and ship building
- Thin walled tubing and pump heads in sea water desalination
- Cladding in construction
- Coatings for machine tools
- Various automotive components including exhaust systems
- Armour plating for land and sea-based military applications
- Various consumer goods including golf clubs, bicycles and jewellery

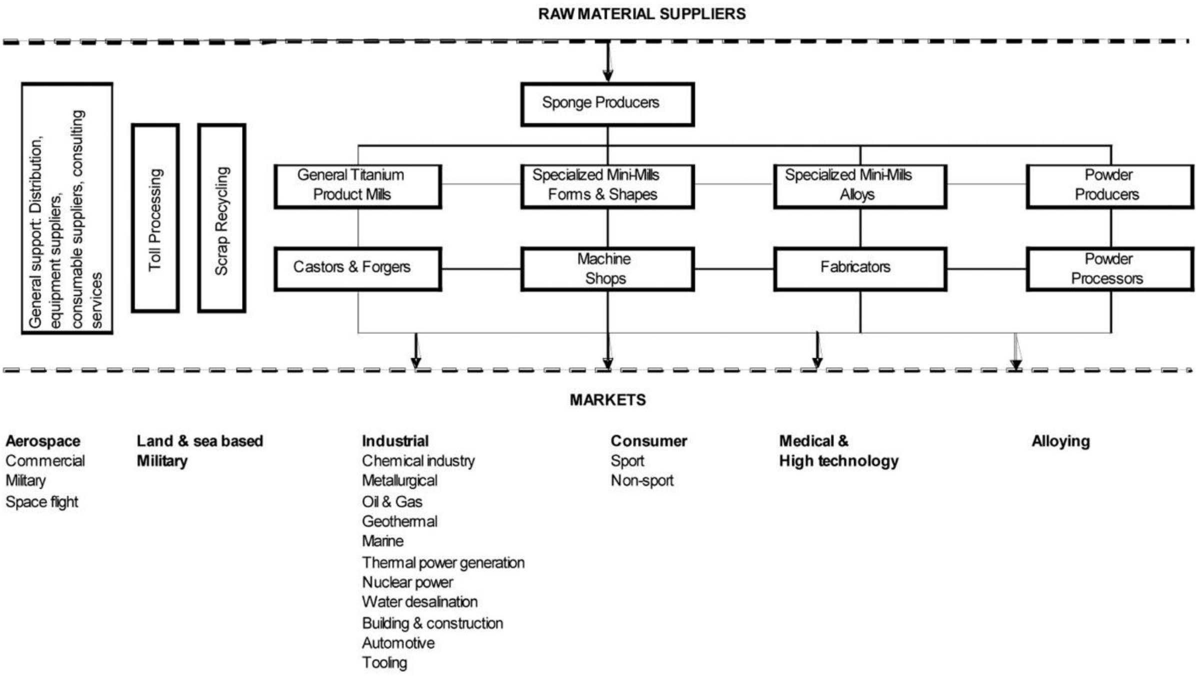


Figure 7: Structure of titanium metal industry (Van Vuuren, 2009)

The various applications of titanium can be grouped into six markets – aerospace, industrial, medical, consumer, non-aerospace military and alloying as indicated in Figure 7 which briefly describes the titanium metal industry. Historically aerospace has been the principle market for titanium components and it is also the market which the TiCoC is aiming for with South Africa's titanium beneficiation strategy. In recent years, the markets for industrial and consumer applications of titanium have outstripped aerospace in growth in the Far East, particularly in China. However, economically, aerospace still has the biggest impact on demand and costs for titanium products.

2.3.1 Titanium metal market

Before looking at individual application areas for titanium metal, it is important to look at the titanium market. The total consumption of titanium mill products is explored in more detail, looking at which application and which region is the biggest consumer of titanium metal. The future of the titanium metal industry is also looked at.

2.3.1.1 Consumption of mill products

Figure 8, adapted from Roskill (2013), shows a breakdown of titanium use per application for several regions in 2012. The values are estimated based on apparent consumption, meaning they include inventory of mill products that have been purchased for future use – meaning that the consumption data presented here doesn't correlate with finished products produced for that year. The values serve only as a guideline for market size as Roskill (2013) reports that there is practically no reported consumption data for titanium metal in the EU and Far East. From the figure, we see that China is driving the industrial sector to be the largest market by volume for titanium mill products. In South Korea, Japan and other countries the industrial sector is also the largest consumer of mill products; while in the USA & Canada, the EU and Russia, aerospace is still the primary consumer. Figure 9 combines the data to give a global picture of titanium mill product consumption by sector, suggesting that in 2012 the industrial sector alone consumed more than half the worlds produced titanium mill products.

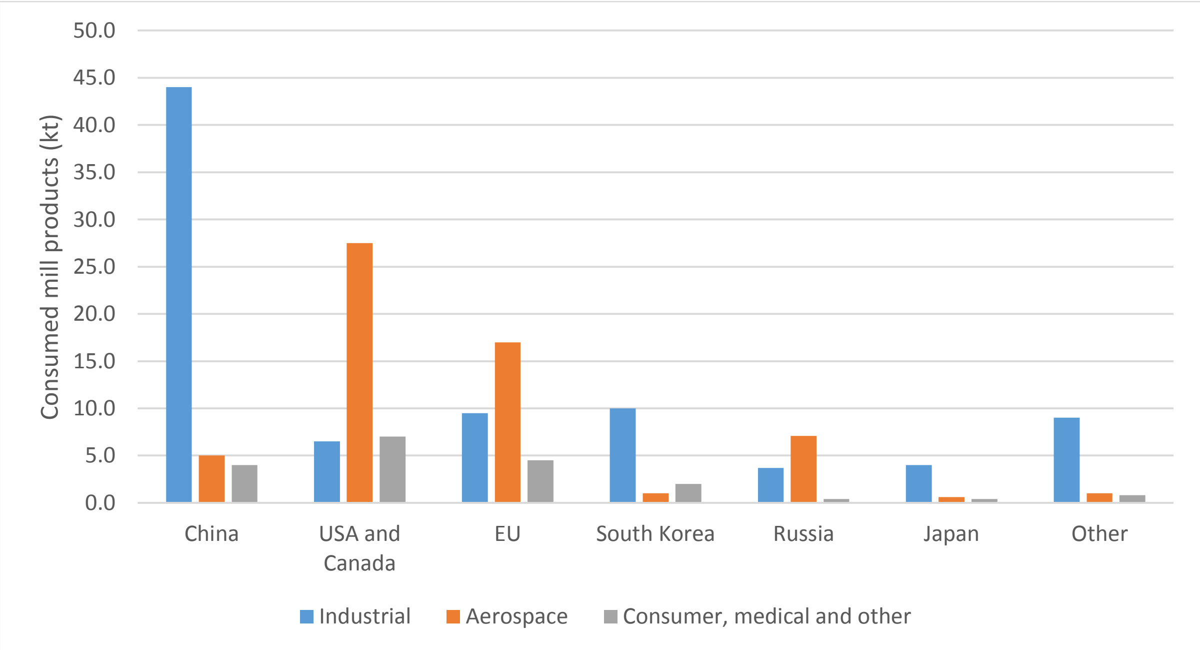


Figure 8: Distribution of titanium mill products consumption by region and application, 2012 (Roskill, 2013)

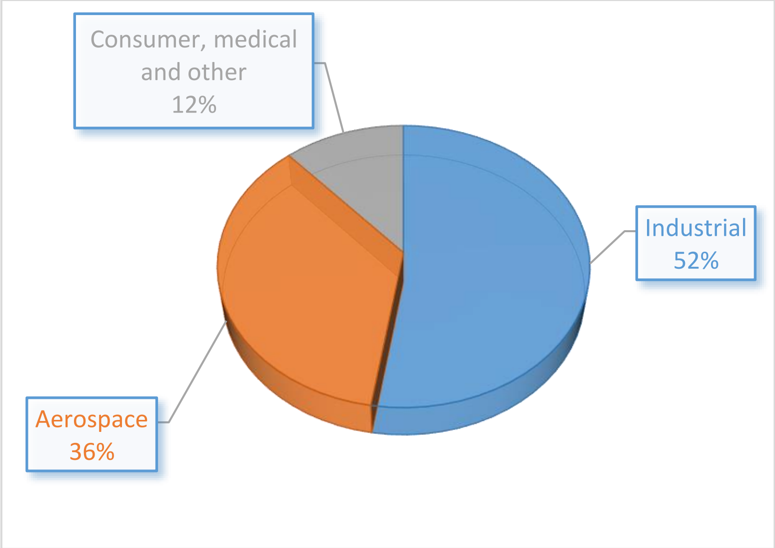


Figure 9: World division of titanium mill product consumption by application, 2012 (Roskill, 2013)

From Figure 8 we can also see that the aerospace sector still dominates titanium consumption in the US while also accounting for most of the consumption in the EU and Russia. The large demand for titanium to the aerospace sector in the US and EU can be put down to the world's two main commercial airframe manufactures Boeing and Airbus, as well major aero engine manufacturers GE, Pratt & Whitney, and Rolls Royce.

The strength of the aerospace sector in the US, EU and Russia can also be gauged by looking at some of the biggest titanium mill product suppliers. Table 5, taken from Roskill (2013), shows the percentage of total capacity of titanium mill products that was shipped to the aerospace sector from VSMPO-Avisma, ATI, Timet and RTI International. In all cases, more than 50% of available capacity was shipped to the aerospace sector. Figure 10 looks at which sectors Timet shipped titanium mill products to in more detail for 2010. In this figure, military aerospace is separated from commercial and instead combined with other military applications.

Table 8: Shipments of titanium mill products to the aerospace sector by supplier, 2012 (kt) (Roskil, 2013)

	Capacity (kt)	**Shipments (kt)**	**% of total**
VSMPO	31.8	20.7	65%
ATI	32.5	17.2	53%
Timet	27.7	16.2	58%
RTI	10.0	7.3	73%

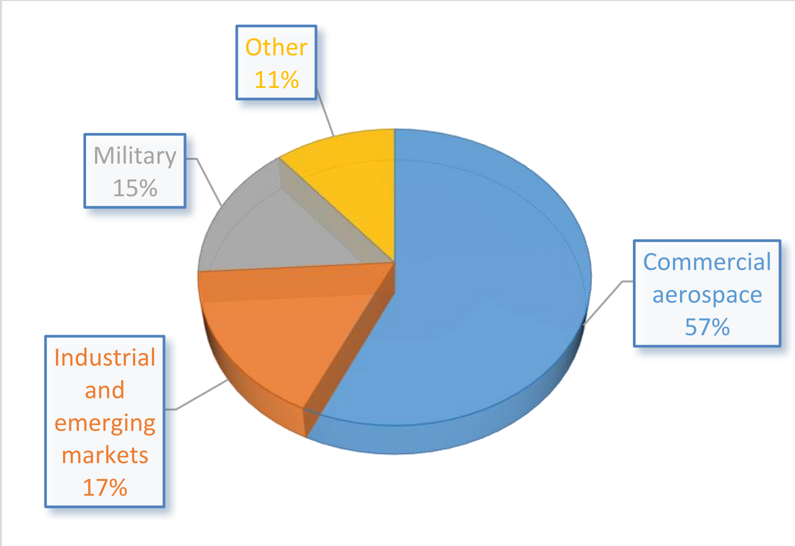


Figure 10: Sectors to which Timet's titanium mill products were shipped, 2010 (Aruvian, 2011)

2.3.1.2 Outlook

The future of the titanium industry is difficult to predict; companies invest large sums of money to ensure they can adapt and prepare appropriately. Aruvian (2011) and Roskill (2013) published detail reports on the state of the titanium industry at the time and estimates for the following years.

Aruvian (2011) identified that the titanium market itself was undergoing a transformation and a change in the variables that influence demand. There existed and still exists a belief that the primary barrier to growth of the global titanium industry, the high costs of production and refinement, would soon be overcome. There was hope that within the next decade a breakthrough would happen, refreshing and dramatically reducing the costs of the titanium value chain.

Aruvian (2011) draws attention to the points observed in the previous section, by recognising that while the importance of titanium has increased for aerospace, the importance of the aerospace industry for titanium has been on the decline. This was seen while the aircraft manufacturing industry was still largest user of titanium metal. Three main demand drivers were identified as the catalyst for previous and continued growth in the prices of titanium products:

- Boeing and Airbus received record levels (at the time) of orders for commercial aircraft during 2005-2006.
- There was a significant increase in the average titanium content per aircraft, amplifying the effect of increased aircraft orders on titanium metal demand.

- In 2003, full time production of the F-22A Raptor causing an increase in titanium demand in the military aircraft sector as well.

Additional factors, not cited by Aruvian but included in a RAND (2009) report sponsored by the United States Air Force, include:

- An increased demand from the industrial sector, particularly in the chemical, power generation and infrastructure sectors in China and the Middle East as well in the oil sector.
- Increased spot market transactions due to higher needs than could be settled by current long term contracts.

Figure 11 shows the Producer Price Index (PPI) for titanium mill products from 1971 to 2015, with estimate for the period from 2009 to 2020 taken from Aruvian (2011). Comparing the estimate from Aruvian (taken from the United States Bureau of Labour Statistics) to actual data till 2015 from the economic research division of the Federal Reserve Bank of St. Louis we see no correlation. In the figure the effect of the previously mentioned factors is evident in the sharp rise in PPI between 2005 and 2007.

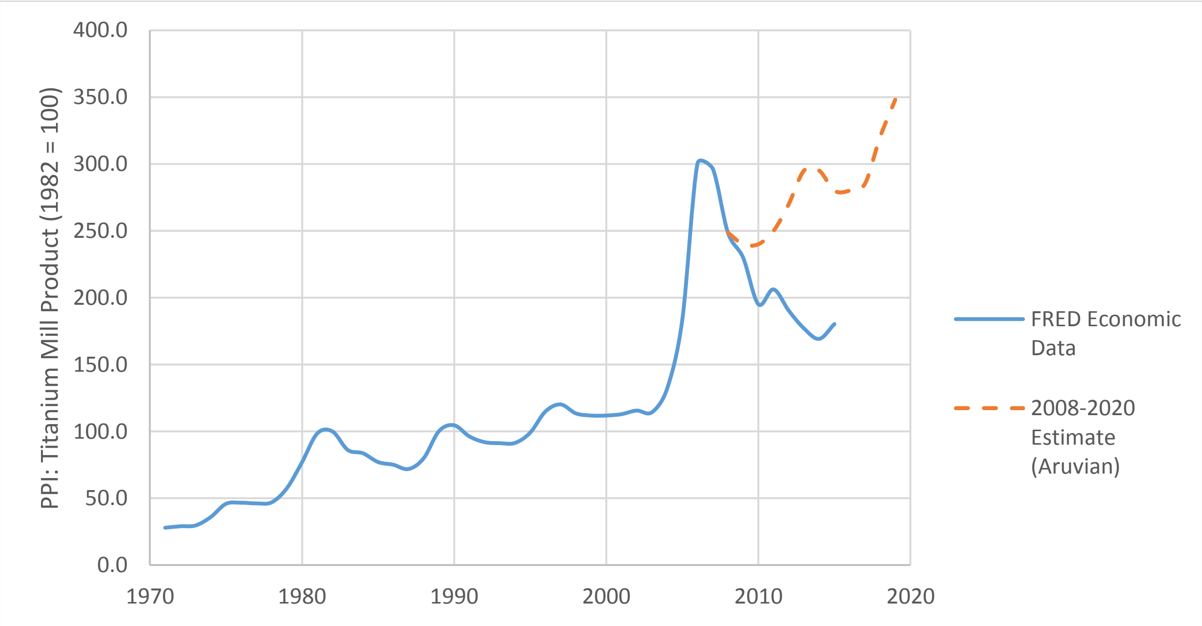


Figure 11: Producer Price Index for titanium mill products 1971 to 2015 (US. Bureau of Labour Statistics. n.d & Aruvian, 2012)

The estimated values from Aruvian (2011) were based on the shift from aerospace to industrial dominated demand. The industrial titanium market is inherently less cyclic than the aerospace market, and it was thought this would stabilise overall demand. It was also argued that the PPI of titanium mill products would not return to its historic average, but would instead grow gradually. The large jumps in estimated PPI were to be the results of significant technological breakthroughs refreshing and transforming the market. If the cost of producing titanium products could be reduced to compete with other structural metals, its superior mechanical properties would allow it to capture a larger portion of the market.

Aruvian (2011) predicted that the global market for titanium would increase by 7% annually from 83kt in 2010 to 124kt by 2015. Roskill (2013) estimated the titanium market to be around 165kt in 2011 and 2012, already far exceeding Aruvian's (2011) expectations. The large growth came on the back of increased industrial demand in China as well as the production of the titanium intense A350, A380 and B787 by Airbus and Boeing in the EU and USA. Roskill predicted growth to slow down to 4.3% annually resulting in a market size of around 216kt by 2015, 74% higher than Aruvian's (2011) prediction. Table 9 and Figures 12 and 13 detail Roskill's forecast for titanium mill product demand to 2018. As can be seen in the table and figures, the industrial sector is expected to have the highest increase in demand, accounting for 74% of the growth. This will primarily be on the back of increase in demand in China, which will account for almost 60% of the growth in demand with expected continued expansion in power generation and chemical applications. Roskill (2013) also predicts that the relatively small expected growth in the aerospace sector will be due to a predicted sharp fall in aircraft deliveries in the early 2020s.

Per Roskill (2013) the global average loss from furnace charge to mill products is approximately 45%, which means a market of 216kt of titanium requires a furnace charge of approximately 390kt – 20% of which may be from titanium scrap. The main part of furnace charge, predicted to be 310kt in 2018, would come from titanium sponge. In 2012 sponge demand was approximately 220kt, not accounting for what goes into inventory, which translates to a predicted growth in demand over the years 2012-2018 of 6%. This growth rate is higher than the growth in demand for mill products because of the decreasing usage of scrap due to availability and the increase in market share of the industrial sector, which inherently produces less scrap.

Table 9: World Forecast demand for titanium mill products, 2018 (kt) (Roskill, 2013)

2012	**EU & NA**	**China**	**Rest of world**	**Total**
Industrial applications	16	44	27	87
Aerospace	45	5	10	60
Consumer & other	12	4	4	20
Total	73	53	41	**167**
AAGR (%)	**EU & NA**	**China**	**Rest of world**	**Total**
Industrial applications	2.5	8.0	4.5	6.0
Aerospace	2.5	5.0	4.0	3.0
Consumer & other	2.0	5.0	2.0	2.7
Total	2.4	7.5	4.2	**4.6**
2018	**EU & NA**	**China**	**Rest of world**	**Total**
Industrial applications	19	70	35	124
Aerospace	52	7	12	71
Consumer & other	13	5	4	22
Total	84	82	51	**217**

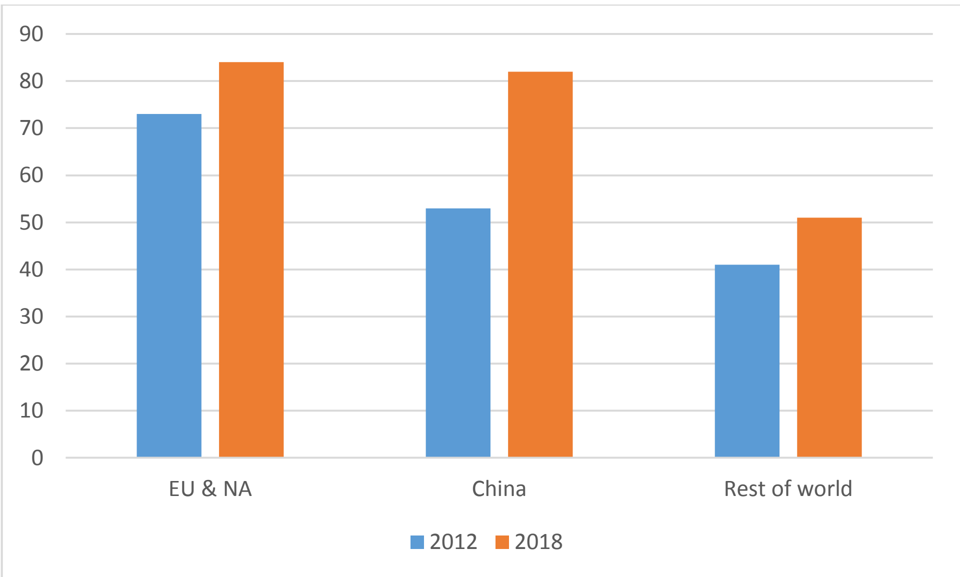


Figure 12: World forecast demand for titanium mill products by region, 2018 (kt) (Roskill, 2013)

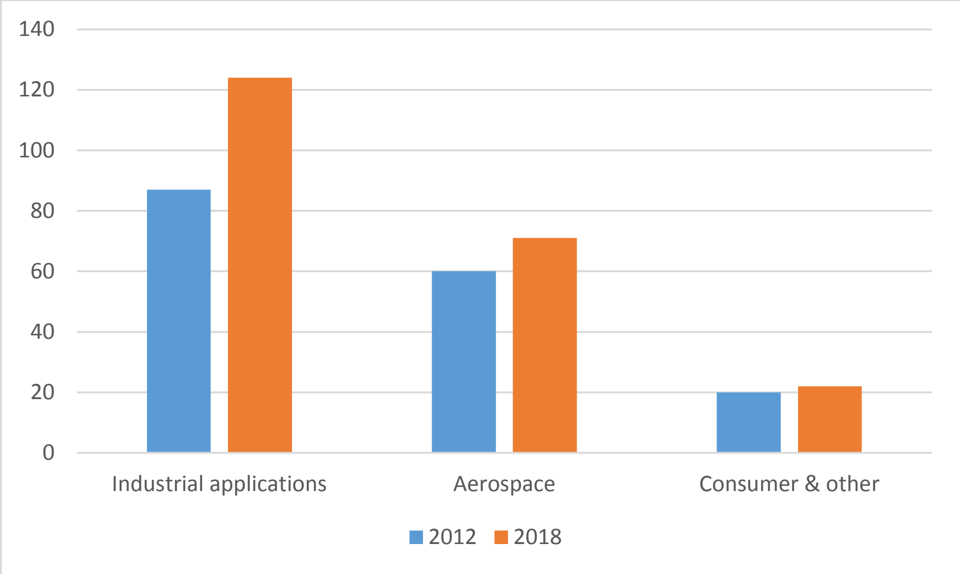


Figure 13: World forecast demand for titanium mill products by sector, 2018 (kt) (Roskill, 2013)

2.3.2 Aerospace

The aerospace industry is the principal market for titanium, accounting for almost 40% of the world consumption, or a buy-in weight of 31kt of mill products in 2009 (Aruvian 2011) and 36% of world consumption, or a buy-in weight of 60kt of mill products in 2012 (Roskill 2013). Global market share for aerospace has dropped since 2009 but total consumption in kt has increased.

The aerospace industry can be broken up into three distinct sections as per Roskill (2013) and Aruvian (2011):

- Commercial aerospace, comprising passenger and freight airliners, regional airliners, and smaller business and leisure aircraft, which accounts for 70-80% of aerospace use.
- Military aerospace, including missiles, small fighter and bomber aircraft, and large transport planes, which accounts for an estimated 25% of aerospace use in the US and about 10% in Europe.
- Space flight, including commercial satellites and space exploration, accounting for less than about 5%

Titanium may cost approximately eight times as much as steel however it's superior strength to weight ratio and compatibility with composites make it the material of choice for many aerospace applications where choice of material is driven by high strength, weight saving and compatibility with composites. Titanium is used in the aerospace industry for components in two areas: airframes – for bulkheads, the tail section, landing gear, wing supports, and fasteners; and engines – for blades, discs, rings and engine cases (Aruvian, 2011). Historically the ratio of use in the two has been 1:1.1 but this is changing with the greater use of composites in airframes, which are more compatible with titanium than aluminium. The airline industry identifies titanium's superior load handling capability over aluminium, minimal fatigue concerns and corrosion resistance as reasons for its use in airframes.

The use of titanium in commercial aircraft is highlighted in Figures 14 and 15. Figure 14 shows the increase in use of titanium as percentage of total weight of the aircraft from 1960 to the present day. The first aircraft with titanium used in major airframe components was the Douglas X3 Stilleto, the engines of the B-52 Bomber and KC-135 Stratotanker were among the first important applications for titanium. The first significant use of titanium in commercial aircraft was in the engines of the Boeing 727, though later versions of both the Boeing 707 and Douglas DC-8 also contained titanium. Figure 15 shows the buy in weight of titanium by type of aircraft for both commercial and military aircraft. Modern large commercial airliners such as Boeing's 787 and Airbus' A350 and A380 have more than six times the buy in weight of titanium compared to early commercial aircraft.

Titanium for use in aircraft components is usually strictly controlled by aircraft companies like Airbus and Boeing, and engine producers like Rolls Royce and Pratt & Whitney. Producers of mill products usually supply the manufacturers directly or supply specialist aerospace manufacturing companies who have been subcontracted to produce specific parts, usually under long term contracts. It is a highly specialised field where companies need to prove they can adhere too strict standards. In addition to mill products being supplied directly to the manufacturers, any scrap generated is usually required to be returned. In South Africa Denel, Aerosud and Daliff Precision Engineering are contracted to produce components for aircraft manufacturers.

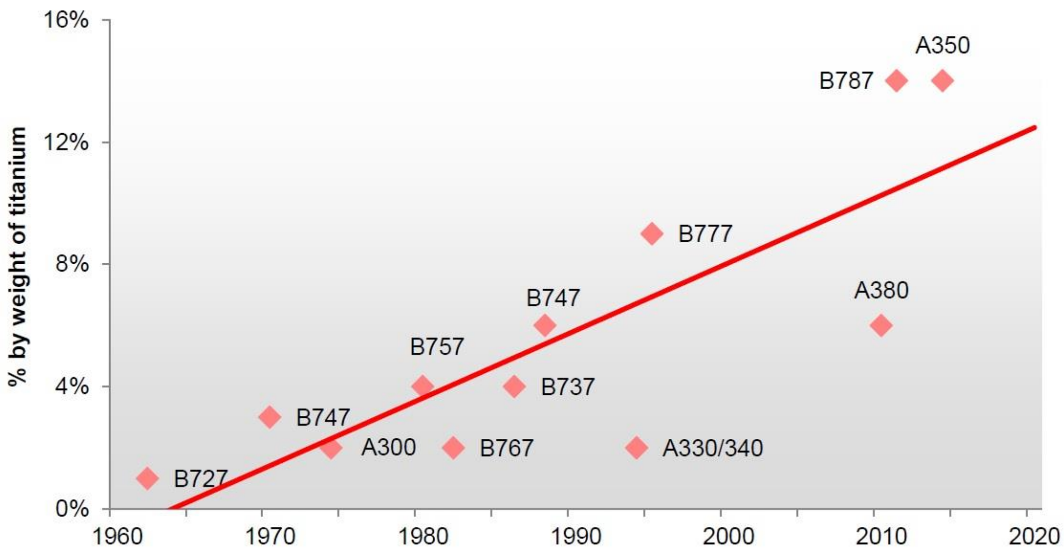


Figure 14: Titanium content per aircraft, 1960-2020 (Roskill, 2013)

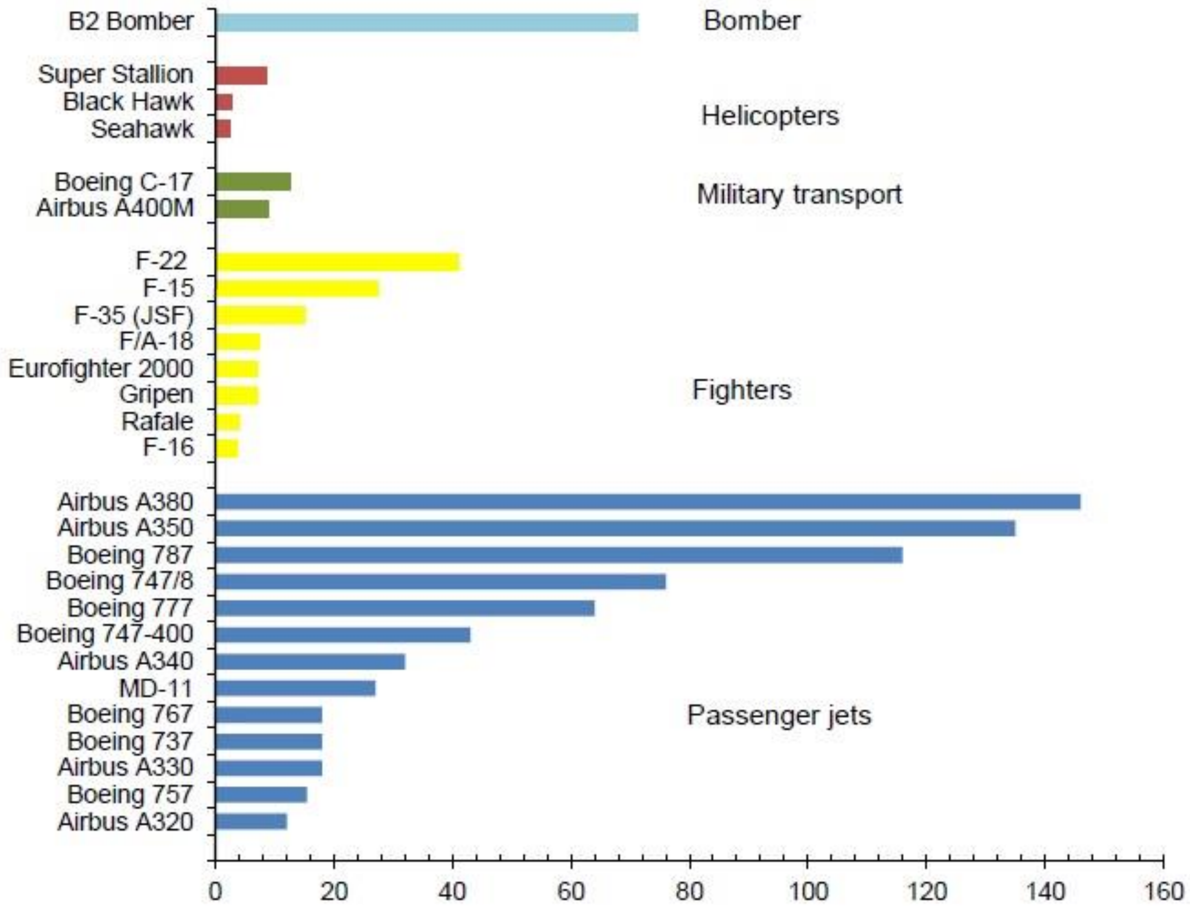


Figure 15: Buy-in weights of titanium by aircraft type, t per aircraft (Roskill, 2013)

2.3.3 Industrial

Industrial applications of titanium encompass all uses that do not fall under aerospace, medical, commercial and military. The industrial sector accounts for the majority, 52% in 2012 (Roskill, 2013), of all titanium mill product shipments and encompasses a wide range of applications in the chemical and petrochemical, oil and gas, power generation, water desalinisation and supply, automotive and construction industries with the single greatest application being plate heat exchangers. The industrial sector is more price sensitive with regards to titanium than the aerospace and medical sectors as material specifications are not as rigid and there is competition from other high performance alloys.

Per Roskill (2013), China accounted for half the global industrial use of titanium in 2012. This was not solely due to the fast pace of economic growth in the region but also a far wider use of titanium over other less costly materials than in the rest of the world. Figures 16 and 17 break down the industrial use of titanium by sector and region. The figures show that most industrial use of titanium is in the chemical and petrochemical sectors and localised in the Far East.

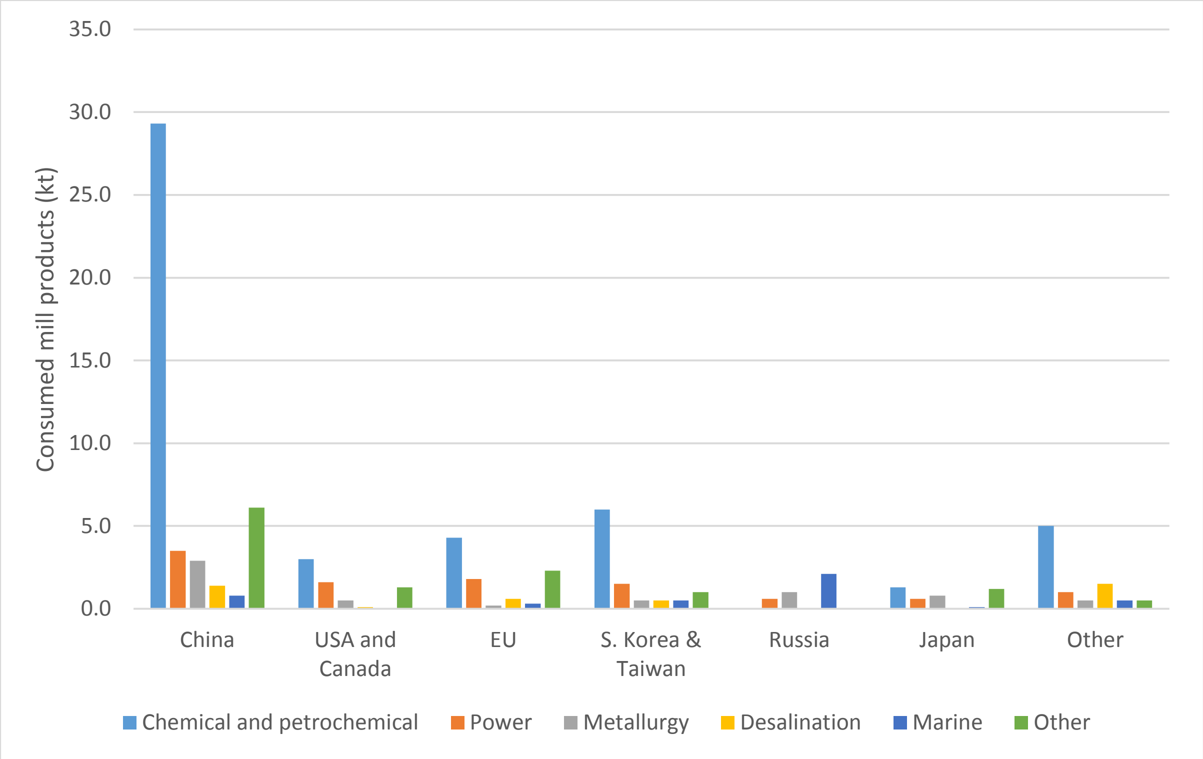


Figure 16: Distribution of titanium mill products consumption by region and industrial application (Roskill, 2013)

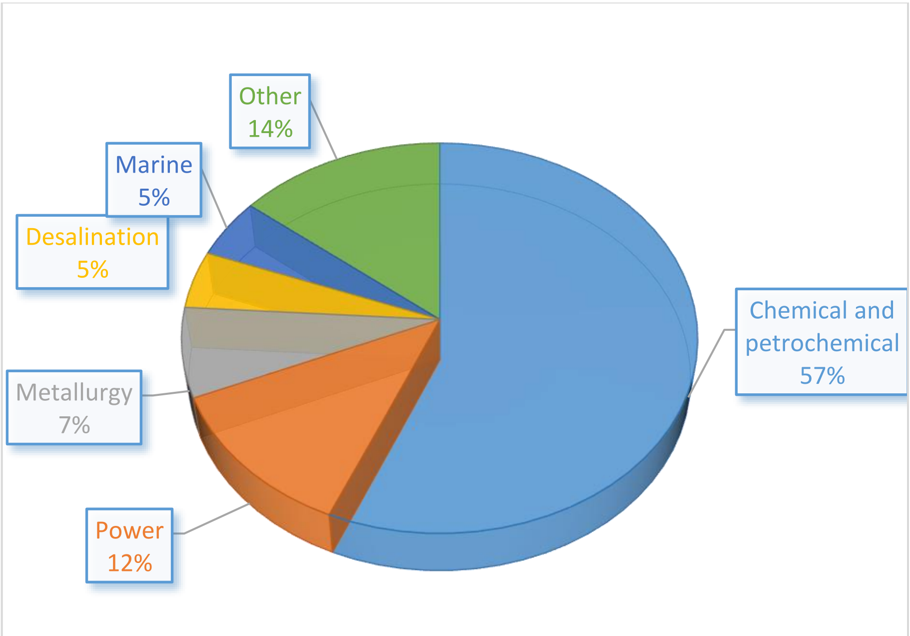


Figure 17: World division of titanium mill product consumption by industrial application, 2012 (Roskill, 2013)

2.3.3.1 Heat exchangers

Titanium is used extensively in surface heat exchangers, where the fluids are separated by a wall. Both plate and shell-and-tube type surface heat exchangers make use of titanium. Such heat exchangers are common in most industries, including food, chemical and petrochemical, power, desalination, as well as air conditioning and refrigeration. Materials such as stainless steel, aluminium alloys, copper-nickel and aluminium-bronze are commonly used for these applications and are all less expensive than titanium and can have a higher thermal conductivity, however they are inferior in corrosive environments. Titanium relatively low thermal conductivity is offset by the ability to have thinner walls separating the liquids due to its superior strength. The thinner walls also result in reductions in size, weight and material requirements. The following advantages of using titanium in heat exchangers are listed by Roskill (2013).

- Higher thermal conductivity than steel
- High cleanliness factor as titanium's smooth surface minimises build-up of fouling films that reduce heat transfer efficiency
- Resistance to local velocities and high pressure caused by blockages
- Immunity to microbiologically influenced corrosion
- Thinner walls and lighter weight
- The promotion of droplet condensation instead of films on its surface, in evaporative processes in brine and nitric acid distillation

2.3.3.2 Chemical and petrochemical

The use of titanium in the chemical and petrochemical processing equipment is primarily due to its high corrosion resistance. Typical processing equipment that makes use of titanium includes vessels, tanks, agitators, coolers and piping, in certain applications titanium is used to clad steel plate to utilise advantages of both and save costs. In certain processes, where conditions are not excessively corrosive, stainless steel is used instead of titanium due to its lower price, in higher-grade end uses titanium competes with materials such as zirconium, tantalum and copper-nickel. Roskill (2013) lists the following corrosive media that titanium is resistant to due to the formation of an oxide film on its surface.

- Chlorine and its compounds – moist chlorine gas; solutions of chlorites, hypochlorites, perchlorates and chlorine dioxide; chlorinated hydrocarbons and oxychloro compounds
- Other halogens – moist gases, aqueous solutions and compounds of bromine; moist gases and compounds of iodine
- Water – fresh, river and seawater; steam; containing organisms that cause biofouling; containing microorganisms that could cause microbiologically influenced corrosion in other materials
- Oxidising mineral acids – nitric; chromic; perchloric; hypochlorus (wet chlorine gas)

- Inorganic salt solutions – chlorides of sodium, potassium, magnesium, calcium, copper, manganese, nickel; bromide salts; sulphides, sulphates, carbonates, nitrates, chlorates, hypochlorites
- Organic acids – acetic; terephtalic; adipic; citric (aerated); formic (aerated); lactic; stearic; tartaric; tannic
- Organic chemicals (with moisture or oxygen) – alcohols; aldehydes; esters; ketonesl hydrocarbons
- Gases – sulphur dioxide; ammonium; carbon dioxide; carbon monoxide; hydrogen sulphide; nitrogen
- Alkaline media – hydroxides of sodium, potassium, calcium, magnesium, ammonium

2.3.3.3 Oil and gas

Starting in the 1990s use of titanium in the gas and oil industry grew rapidly, exceeding 1ktpy (Roskill, 2013). The rapid growth has since been halted mainly due to the high cost of titanium. The main use for titanium in the oil and gas industry is for offshore platforms, using between 30 and 500t of titanium per platform (Roskill, 2013). As oil wells have gotten deeper, the need to save weight has become more critical. Some wells reach several kilometres deep where they used to be only a few hundred metres. Titanium's light weight, tensile strength and flexibility make it ideal for allowing platforms to withstand and move about with ocean waves.

Titanium is extensively used in tension leg platforms, in the following areas (Roskill, 2013):

- Tapered stress joints
- Production risers
- Keel joints
- Catenary risers
- Tree jumpers
- Coiled tubing

Titanium is primarily used in longer term projects, lasting 20 to 30 years, as its use improves cost efficiency. In short term projects, cheaper alternatives such as carbon steel are used as they will survive the life of the project. Titanium use in tapered stress joints is preferred as they are a third of the length, have half the wall thickness at the root, have a third of the bending moment to the vessel and are not sensitive to small increases in angle requirements and have better fatigue properties (Roskill, 2013).

Per Roskill (2013) the widest use of titanium on platforms is for various forms of tubing, typically platforms can contain 50 to 150t of titanium topside piping. It has good corrosion resistance to seawater, oil and gas; a low weight (a typical weight saving for 3km of drilling riser is 3.6t in the ‘choke and kill’ lines and 47t in the foot joints; a lack of design limitations; and high flexibility and yield strength. Titanium tubing is also reusable, recyclable and more environmentally friendly.

2.3.3.4 Nuclear

Titanium has a wide variety of applications in the nuclear power generation field. Most existing nuclear power stations contain little to no titanium components as titanium was not readily available in suitable and affordable forms during the periods of their design and construction. In the modern day, however, titanium – particularly in the form of seam welded tubing – has found an increased use. The primary application for titanium in nuclear power generation is in heat exchangers. Titanium tubing can be found in condensers, low and high-pressure feed water heaters as well as moisture separator reheaters (MSRs). Its superior corrosion resistance over conventional copper tubing reduces the risk of hot spots and cracking forming on reactor rods caused by deposits of corroded material. A further application of titanium in the nuclear power generation industry, and in fact any thermal power industry is, is for the construction of steam turbine blades. Advantages of titanium blades include resistance to corrosion fatigue and stress corrosion cracking, reducing risk of failure and resulting generator downtime (Roskill, 2013). Titanium is also used in small quantities to encase concrete container in which nuclear waste is buried. The main advantage of titanium over other materials is corrosion resistance.

Per the International Energy Agency (IEA), nuclear is expected to be the fastest growing major fuels source for power generation until 2025. There were 68 nuclear power stations under construction in March 2013, including: 28 in China; 11 in Russia; 7 in India; 4 in South Korea and 3 in the USA (Roskill, 2013).

2.3.4 Medical

Titanium use in medicine started as early as the 1950s and Roskill (2013) estimates that the global market for titanium in medicine was around 3 ktpy in 2010. Titanium has many applications in the medicine both biomedical and for medical equipment. Some of the uses (expanded from Roskill, 2013) include:

- Bone and joint implants and replacements, including – hip and knee prosthesis; spinal implants and cages; pins, screws, plates, bars, rods and wires and other internal fixators; digit replacements and facial prosthesis
- External fixators, including – prosthetic limbs and orthotic callipers
- Cardiovascular applications, including – heart valves, vascular implants such as stents, pacemaker cases and implantable defibrillators
- Dental implants

- Medical equipment, including – wheel chairs and surgical instruments such as forceps, retractors, tweezers, dental drills, Lasik eye surgery equipment, clips and needles

Titanium is beneficial in medicine not only because of its strength, light weight and corrosion resistance; but also, due to it being non-toxic, biocompatible (it will not be rejected by the human body), long lasting, non-ferromagnetic, promotes osseo-integration and has flexibility and elasticity like human bone.

Titanium is an expensive material for biomedicine but is widely regarded as the best material in many areas. Per Roskill (2013) titanium is used because it has proved to be completely inert and compatible with bodily fluids and tissue. Titanium implants longevity is also an important factor as these can last for upwards of 20 years in the case of cages, rods, plates and pins and even longer for dental implants. Titanium's radiolucency allows patients with implants to safely undergo computed tomography (CT) scans and be examined with magnetic resonance imaging (MRI).

2.3.5 Other application areas

2.3.5.1 Consumer

Titanium is widely used in consumer applications per Roskill (2013) the global consumer market for titanium in 2012 was of the order of 10 kt of mill products. Unlike in other application areas of titanium where titanium's light weight, strength, corrosion resistance and flexibility are key drivers for its use, the aesthetic qualities of titanium are also a key characteristic for consumer use. Roskill (2013) identifies the following key consumer applications for titanium:

- Golf clubs
- Bicycles
- Spectacles, sunglasses and jewellery
- Watches, cameras, binoculars and accessories
- Art and art materials
- Kitchenware

Golf clubs make up the largest segment of consumer use of titanium, more than the other applications combined. Per Roskill (2013), virtually all "metal wood" golf club heads are made of cast titanium. Due to its strength-to-weight ratio, titanium allows for much bigger club heads without exceeding the allowable weight than stainless steel. Titanium is also used in golf club shafts, however here it faces extreme competition from cheaper materials such as steel and graphite/epoxy.

Another sporting application of titanium is specialised bicycles. These provide a small yet high value added market for titanium, higher than any aerospace or industrial uses. Titanium is used for both bicycle frames and components (Roskill, 2013). The large number of components however only translate into a relatively small market. Other sporting applications include baseball bats, lacrosse and hockey sticks, skis, ice and roller skates, tennis rackets, darts and others.

Outside of sporting applications titanium is extensively used in spectacle frames, with some seven to 8 million of these sold annually worldwide, each using approximately 32g of titanium (Roskill, 2013). Titanium is also used extensively in jewellery, including in rings, necklaces, earrings, brooches and bracelets due to the interference colours produced when white light interacts with the thin oxide layer that forms on the surface of titanium.

Titanium is used as a non-stick coating in kitchenware that is also highly corrosion resistant, has an appealing finish like stainless steel and high strength and hardness making it damage and scratch resistant. Per Roskill (2013) kitchenware would be one application that would quickly benefit from a decrease in titanium costs. Roskill (2013) lists the following advantages for titanium in kitchenware:

- Does not leach metal into food
- Lightweight and easy to handle
- Provides fast heating response
- Is scratch and dent resistant

2.3.5.2 Automotive

The automotive industry is a huge market however titanium applications remain limited due to high costs and difficulty of fabrication. Per Roskill (2013) among others titanium is used in the automotive industry in the following applications:

- Exhaust systems
- Suspension springs
- Valves and valve springs
- Brake pads
- Racing and high speed cars
- Concept cars

While the prospect of widespread use in the automotive industry has been a key driver behind the quest for lowering titanium production costs, per Roskill (2013) it is unlikely to ever rival aluminium as the dominant lightweight material. Titanium’s strength and weight would be highly advantageous to the industry, however, the fabrication costs and risk associated with redesigning systems to accommodate titanium are too great. If titanium where to become an integral and standard part of an automotive engines, it would lock-in its use and tie production costs to the cost of titanium, and would it would be expensive to design titanium back out should material costs soar. Titanium in general is used as a specialist material, for low volume production of specialised components. This is the opposite of how the general automotive industry operates, where large volume production of standardised components is common place.

2.4 Summarising economic and strategic considerations

In this section, we look at the titanium value chain, titanium reserves and mine production as well as the titanium metal market; we also look at different application areas for titanium machined products. Key points to take away include:

- The vast difference between the price of titanium in its primary form and as a finished product, highlighting the significance of titanium machining to the value chain as a whole
- The loss of potential value-add due to South Africa’s limited involvement in the value chain
- South Africa’s present position as holder of the world’s fourth largest titanium reserves
- South Africa’s position as the world second largest producer of titanium product
- China is the world’s largest consumer of titanium mill products, followed by USA and Canada, and then the EU.
- While most of USA and Canada, and EU titanium mill product consumption is for the aerospace sector, Chinese mill product consumption is almost entirely (more than 75%) in the industrial sector
- The industrial sector is the largest consumer of mill product globally

The above points provide guidance in whether South Africa should invest more in the titanium industry and where to focus investment.

3. Socio-economic aspects

This chapter deals with the socio-economic climate of South Africa. Focus is placed on identifying challenges facing the country and determining where improvement is necessary to take the country forward. The findings of the National Planning Commission that led to the development of the National Development Plan 2030 are explored and the links between them and key problems identified by the Boston Consulting Group are looked at.

3.1 Development of the National Development Plan 2030

In April 2010, South African president Jacob Zuma appointed the National Planning Commission (NPC, 2011) with the mandate of taking a broad, cross-cutting, independent and critical view of South Africa to help define where South Africa needs to be in 20 years' time and to map out a path to achieve those objectives. The NPC consisted of 26 individuals, mostly not from government, chosen for their expertise in key areas; and was required to work with broader society and relevant stakeholders to draw the best expertise and put forward research, evidence and recommendations on how to deal with the challenges facing SA. The NPC was tasked with (NPC, 2011):

- Drafting a vision statement for 2030
- Producing a development plan setting out path to achieve this mission
- Presenting reports on issues affecting long-term development of the country

This section will deal with the results of the NPCs ground work, which is laid out in the NPCs Diagnostic report published in June 2011 (NPC, 2011). The NDP was developed to solve the challenges identified by this diagnostic report through public consultation and input from parliament, the judiciary, national departments, provincial governments, development finance institutions, state-owned entities, local government formations, unions, businesses, religious leaders and non-profit organisations.

With the end of apartheid South Africa embarked on road with the aim of becoming a prosperous, united, non-racial and democratic country with opportunity for everyone, irrespective of race or gender. The NPC (2011) identified that while the country had been making progress, this objective could not be achieved by continuing its current course; for many South Africans, excluded from the formal economy, living in informal settlements and dependent on poor quality or non-existent social services, the political transition has not translated into a better life. The NPC (2011) identified nine primary challenges, as listed below and shown in Figure 18, standing in the way of progress.

1. Too few South Africans are employed
2. The quality of school education for black people is poor

3. Infrastructure is poorly located, inadequate and under-maintained
4. The economy is unsustainably resource intensive
5. Spatial divides hobble inclusive development
6. The public health system cannot meet demand or sustain quality
7. Public services are uneven and often of poor quality
8. Corruption levels are high
9. South Africa remains a divided society

In the diagnostics report the NPC (2011) explored each of these challenges, providing historical context and identifying their effects. As shown in Figure 6 the NPC highlighted eliminating poverty and reducing inequality as key strategic objectives for the future and thus these would be key objectives of the NDP.

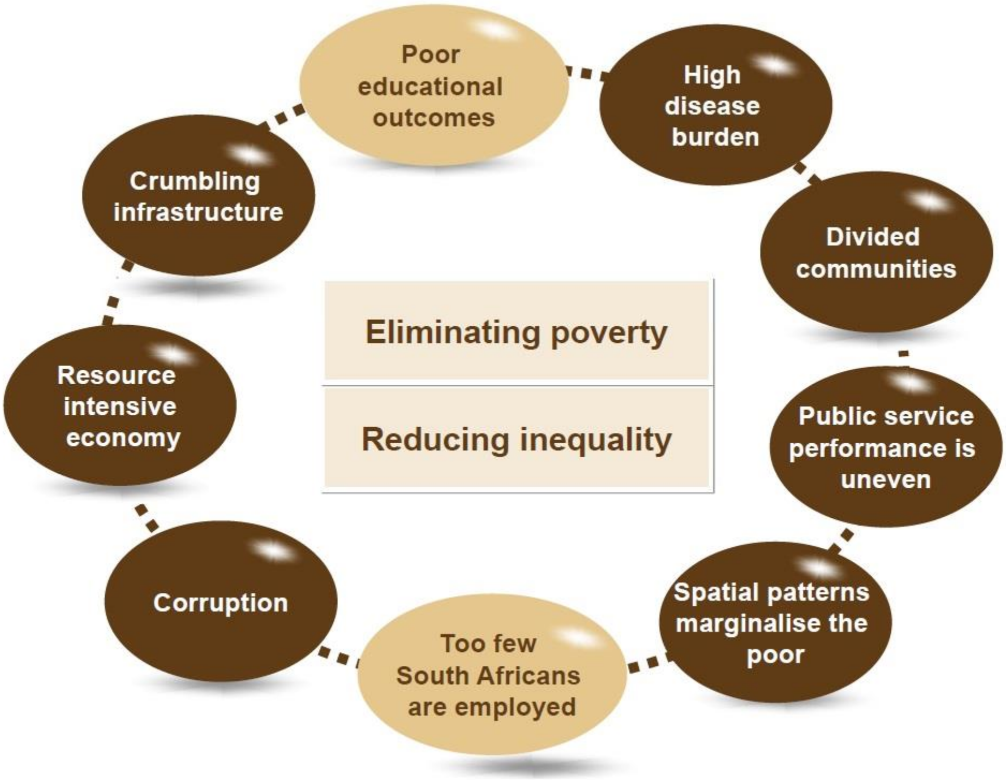


Figure 18: Primary challenges and strategic objectives (NPC, 2011a)

The challenges relating to unemployment, education, infrastructure, spatial divides, the resources intensive economy and healthcare can have a significant impact on titanium beneficiation and in turn be affected by it and will therefore be explored in more detail. This does not take away from the significance or potential impact of the remaining challenges, however they were considered outside the scope of this study. The findings of the NPC (2011) relating to the relevant challenges are summarised in the following sub-sections. Some of the statistics presented in the diagnostics report are outdated and no longer relevant but are presented here as they form part of the base on which the NDP was drafted and are useful to track progress between when issues were highlighted with the release of the NPC report and the current situation as explored in Section 3.2. To put the findings of the NPC in perspective, the responses of independent experts not involved in the commission for the diagnostics report are presented in each subsection.

3.1.1 Unemployment

South Africa has an extremely high unemployment rate (25% in 2010), driving poverty and inequality. One of the key obstacles to improving the unemployment rate that the number of labour market entrants is constantly growing. Despite positive job creating growth between 1997 and 2008, where for every 1% growth in GDP there was a 0.6 to 0.7% growth in employment (the average for successful emerging economies was 0.3 to 0.5% employment growth per percentage GDP growth), growth in the labour force had outstripped growth in employment for several years. This was partly the result of demographic shifts, as large numbers of women and young people entered the job market. The youth of South Africa is most severely affected by unemployment, with two thirds of the total unemployed below the age of 35. Figure 19 shows the total percentage of the available workforce that is unemployed from 2001 to 2012 and Figure 20 shows the number of discouraged job seekers per age group as determined by the DPME. Unemployment peeked around 2002, and over half of those between the ages of 15 and 24 are unemployed and around 30% of those between the ages of 25 and 34. (NPC, 2011)

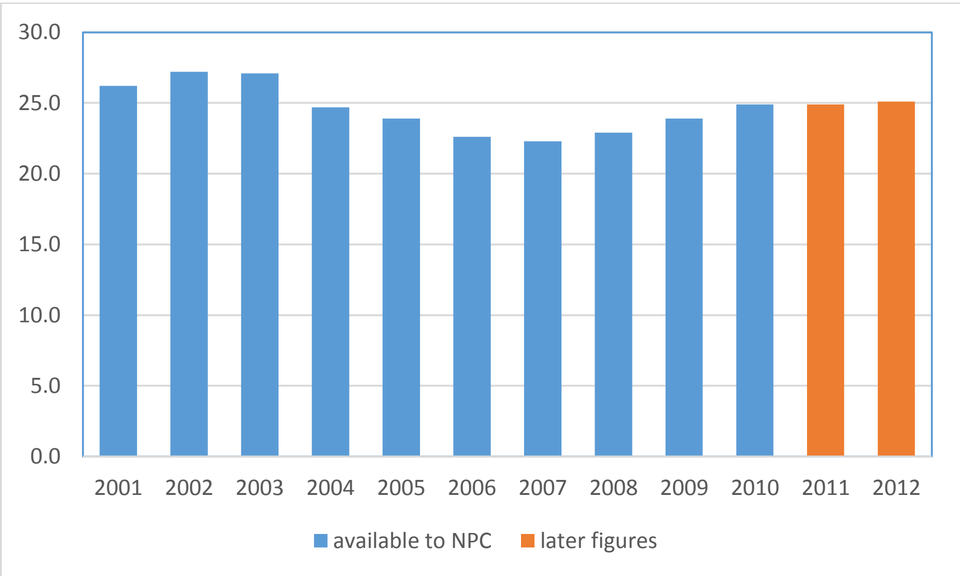


Figure 19: Percentage of workforce that is unemployed, 2001-2012 (DPME, 2013)

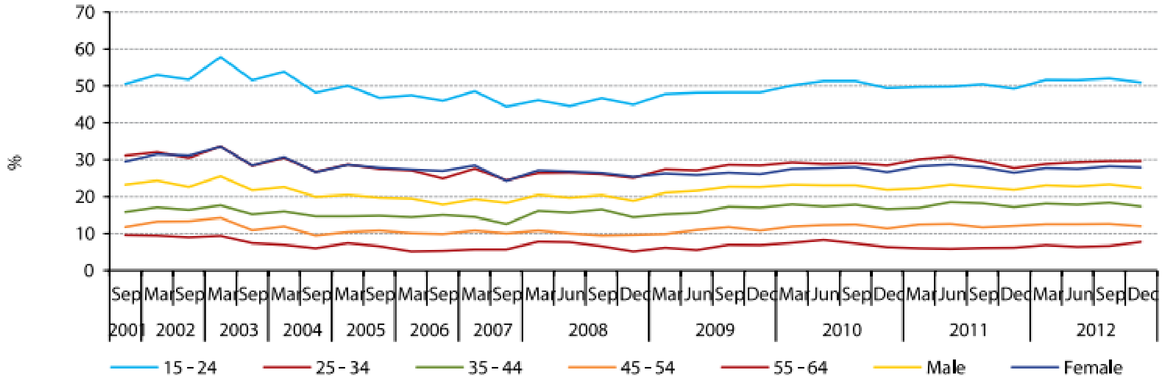


Figure 20: Percentage of unemployed by age, 2002-2012 (DPME, 2013)

In South Africa, it is only compulsory to attend school up to the age of 15, and many young South Africans do not finish matric and are not sufficiently prepared for further training or work. Those from poorer backgrounds who do choose to continue education or find work regardless are often left as the sole breadwinners for several dependents; this will be looked at further in Section 3.4. South Africa is considered a middle-income economy and has a cost of living that reflects this status, thus the pressure of a high dependency ratio on low wage earners leaves many working households around the poverty line; despite improvement from 53% in 1995, 48% of people still lived below the line in 2008. Half of those who were employed in 2008 earned less than R2500 per month, while one third earned less than R1000. Adding to the difficulties faced by the poor due to a high cost of living, is a high “cost of working” due to diffuse settlement patterns and weak public transport. Limited access to affordable food and high quality public services compound the problems (NPC, 2011).

Only 41% of the working age population is working, which is well below the average of similar countries, and almost 60% of the unemployed population has never worked. Growth in employment has been concentrated in less labour-intensive sectors. Between 1970 and 1995 employment in the mining and agriculture sectors shrank by 46% and it was only from 1997 that opportunities for low and semi-skilled workers expanded; these were primarily in the services sector – security, cleaning and personal services. South Africa is primarily a mineral exporting economy making it difficult to expand labour absorbing tradeables. Mining and related products account for a large proportion of total exports without making a significant contribution to employment. South Africa’s economy is primarily supported by income from high commodity prices, which is not sustainable in the long term. It undermines the country’s ability to develop the downstream manufacturing industries needed for long term expansion. Long term success is dependent on expanding our global share of value-add. In successful economies, small, medium and micro enterprises (SMME) are key to job creation, however South Africa has laid the groundwork for the creation and growth of such enterprises; an onerous regulatory environment, limited access to finances and capital, and concentrated markets with limited opportunities for niche companies are among the obstacles experienced. Growth has been consumption led which, while beneficial for job creation in the short term, is fuelled by imports that need to be paid for or backward linkages into domestic production and cannot be sustained long term by a small economy (NPC, 2011).

A major problem for those seeking to change their situation is that they do not possess the skills required by the modernising economy. Higher education institutions are not producing the number of skilled personnel required, raising the cost of those who do have the skills. There are many low and semi-skilled jobs being generated by the economy however these require a certain set of capabilities which many available workers do not possess due to dropping out of school early, for example reading comprehension. As the number of matric graduates expands, employers are increasingly requiring matric as a minimum, turning away those that would have previously been hired – creating a "credential inflation" without the accompanying rise in earnings or skill requirement. The lack of job readiness is a strong disincentive to hiring young people and it is becoming increasingly expensive to further train and prepare (NPC, 2011).

In South Africa, the labour market is highly segmented, consisting of:

- A core of well-organised sectors and public servants
- A larger periphery of vulnerable unorganised and low-paid workers in the formal and informal sectors
- A marginalised group of unemployed

Labour regulation provides basic protection and rights to the first two groups – sector minimum wages, requirement of employment contracts, the right to organise, second-tier social security benefits and protection against unfair discrimination. Mechanisms for dispute resolution have also been put in place to reduce the role and need of courts and attorneys however this has led to rising costs to firms in terms of lost time and income, the mechanisms are also often log-jammed by those who are least vulnerable (e.g. professionals). Labour regulations have also had other negative consequences such as making it difficult to sanction poor performers, resulting in less incentive for firms to hire inexperienced workers, compounding the high youth unemployment problem (NPC, 2011).

Independent experts agree and disagree with the NPC's findings to varying degrees but all highlight the importance of entrepreneurship in tackling unemployment. Sharpe (2011), presents an opposing view to the to the present unemployment climate in South Africa. Sharpe (2011) claims that South Africa's unemployment rate increased from 7% in the mid-1970s, to

13% in the mid-1990s and 25% in the late 2000s implying that current unemployment levels are largely a post-apartheid phenomenon. He claims that accepting this fact is a necessary first step in fixing the problem as it will steer the country away from believing that the only way to address unemployment is by addressing the legacy of apartheid itself. Per Sharpe (2011) many South Africans have been incorrectly labelled as unemployed; claiming that the size and impact of informal employment has been substantially underestimated and that if it is properly accounted for could put South Africa's unemployment closer to 8%. Informal employment is not dependent on government initiatives and policies, does not contribute to taxation, and does not adhere to labour laws; but does suggest that many millions of enterprising South Africans make a living daily. Addressing unemployment rests per Sharpe (2011) in unravelling the post-1994 changes that have caused unemployment to double; and bringing millions of informally employed South Africans into the formal sector. To achieve this, two areas of the Labour Relations Act of 1995 (LRA) need to be addressed, in this case Mr Sharpe largely agrees with the findings of the NPC; these two areas are collective bargaining procedures and protections against dismissal. Baets (2011), believes that South Africans needs to escape the trap of blame and entitlement and reframe the way unemployment and other social problems are thought of to find a way out of the present crisis. Baets (2011) argues that taking on unemployment and social challenges should be a massive business opportunity modelled on the research and writings of Michael Norton. Norton (2007) identified three specific stages that are necessary in successfully tackling seemingly insurmountable social problems:

1. Social invention: generating innovative ideas in response to problems and needs
2. Social entrepreneurship: turning ideas into working solutions
3. Social enterprise: creating enterprising solutions that enable the projects to grow and scale up

Oosthuizen (2011), believes that a national strategy on entrepreneurship could offer a solution to the unemployment figure and highlights the staggering youth unemployment rate. To achieve this there is a need for a unified national centre consisting of both public and private sector stakeholders to bring about such a strategy and to align commitments, provide common goals on a macro level and lead and coordinate micro initiatives across the country. Oosthuizen (2011) states that an "entrepreneurial transformation" is required, which entails a fundamental change in how South Africans perceive, think and behave in terms of entrepreneurship, its function and how it relates to the larger economy.

3.1.2 Education

On the face of it education in South Africa appears to have undergone many positive reforms. Access to and participation in education has increased to the point that it is almost universal.

There are 14 million learners enrolled in school, 96% of whom are in publicly funded or government schools. In 2007 gross enrolment was 92% overall, with a 98% enrolment for grades one to seven, and an 85% enrolment for grades eight to 12. In general, there has been an increase in literacy rates since 1994. There has also been an improvement in equity in expenditure per pupil which is important as it leads to broadly uniform average class sizes, equivalence in teacher pay, an increase in the number of teachers (who have at least a three-year qualification) in predominantly black schools, and a funding model that supports the provision school books. Despite these improvements, the quality of physical assets and infrastructure at schools remains highly unequal, with many lacking toilets, electricity, desks and chalkboards. In 2006 there were 5000 schools without access to electricity and 500 without on-site toilets (NPC, 2011).

High enrolment and improved equity in funding only mask an underlying problem in education in South Africa. The quality of education for poor children in general remains very poor; there is only a small minority of black children attending former white schools and a small minority of schools in black areas that are performing well. Literacy and numeracy test scores are not only low by global standards, but also by African standards; this is despite South African teachers being among the highest paid in the world and the government spending around 6% of GDP on education. There is a trend that learners in historically white schools not only perform better, but also improve with successive years of schooling, while the schools with mostly black learners start with lower scores that see relatively little improvement between grades three and five. Test scores at schools in poorer communities are understandably lower than their wealthier peers, however they are also significantly lower than the scores achieved by poor learners in other African countries. There have been improvements in matric pass rates, with a 67.8% pass rate achieved in 2010; this statistic however hides the fact that only 15% achieved a mark above 40% accounting for only 7% of those born between 1990 and 1994. Figure 21 shows a comparison in performance between predominantly black high schools and other schools in the 2004 mathematics senior certificate results; only 1% of black schools are top performing on high school certificate results compared to 31% for formerly privileged schools – schools are categorised per (NPC, 2011):

- Top performing - produce at least 30 maths passes, with at least 20% at higher grade
- Moderately performing - produce at least 30 maths passes, mostly at standard grade
- Poor performing - fail to achieve 30 passes in math

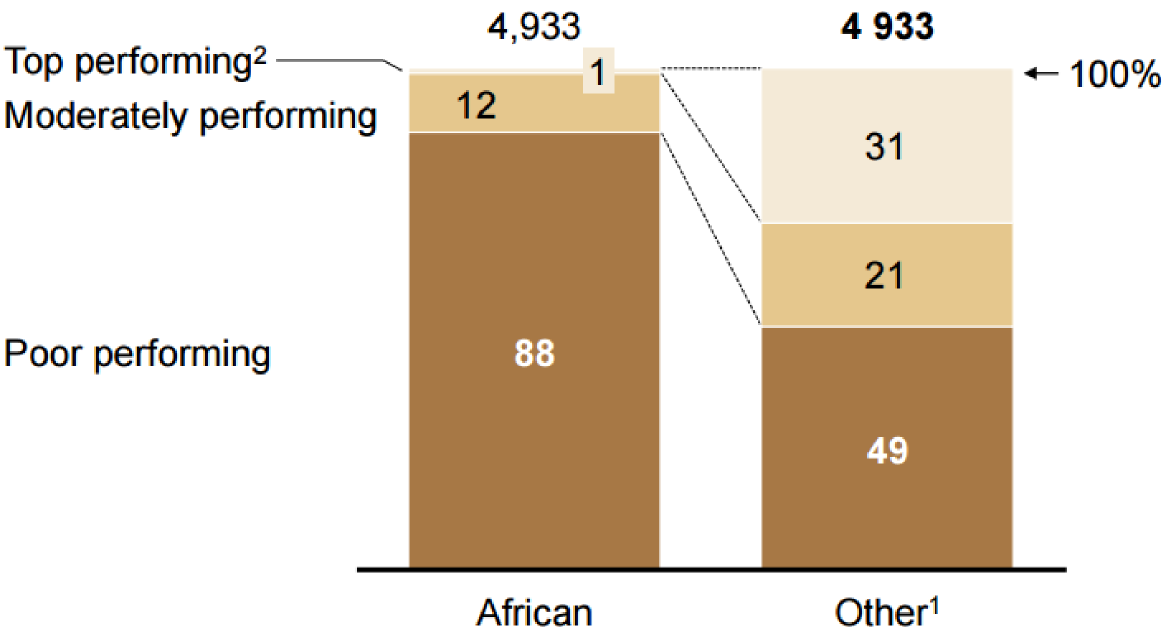


Figure 21: Distribution of high schools by performance in Senior Certificate for Mathematics, 2004 (NPC, 2011a)

There are long-term studies that show a correlation between literacy and numeracy scores at age seven and earnings at age 30 and a general belief that a child's deductive ability is formed before they enter school and that learner performance is not solely dependent on what happens at school. The socio-economic situation at home has an influence on performance of learners, important factors include (NPC, 2011):

- The presence and literacy of both parents
- Prevalence of books and other learning materials,
- Adequate nutrition and intake of micronutrients,
- Generally stimulating environment.

There is often an absence of these in poorer households resulting in poorer performance compared to wealthier peers. To overcome the unevenness in household background of learners, many countries have introduced early childhood education programmes as a relatively low cost means of raising standards. Such programmes were practically non-existent in black communities before the mid-1990s. The phasing in of Grade R for five year olds and the expansion of early childhood education has led to an increase in learner numbers; in 1996 only 22.5% of five year olds where enrolled in an educational institution, by 2001 this had risen to 45.6% and by 2007 to 80.9%; participation among six year olds has risen from 49.1% in 1996 to 91.4% in 2007. Today on top of the 80% of five year olds enrolled in Grade R, around half of the children below the age of five already receive some form of preschool education. In poor black communities, the quality of early childhood education and care is poor and inadequate. Despite policy commitment to such programmes, implementation in the poorest communities is lagging. Many are underfunded by the government and need support from donors to nongovernmental organisations. Many children in the in schools in poor communities receive a meal, which contributes to raising nutrition levels in poor communities (NPC, 2011).

Per the NPC (2011), the main problem lies not in the social and environmental conditions but in the education system itself; several factors have a significant impact on the quality of education:

- Constantly changing curricula, and the design of the curriculum itself
- Type of teacher training
- Support provided to teachers
- Time spent teaching compared to other activities
- Availability of teaching and learning materials
- Language issues
- Use of technology
- Efficacy of bureaucracy
- Balance of power between parents, teachers and bureaucracy
- High levels of violence against women and children

While these play an important role, the most significant factor is the performance and quality of not only the teachers themselves, but also school leadership. Comparative studies on school performance in South Africa and studies of successful practices in countries that face similar challenges suggest that these are the most important factors influencing poor performance at South African schools. The NPC (2011) claims that in-depth studies conclude that teachers spend too little time in contact with learners, possess inadequate subject knowledge and basic pedagogical ability (especially in languages, science and mathematics), are poorly supported by administration and have their task made harder by the sporadic availability of books and learning material. The Human Sciences Research Council has found that almost 20% of teachers are absent on Mondays and Fridays, even more at month-end. Teachers in black schools spend significantly less time teaching than in white schools, 3.5 hours compared to 6.5, amounting to a loss of around three years of schooling. School administration in poor communities lacks the ability to provide counselling and support services to pupils from households without both parents, without income support, and whose daily lives are shaped by violence, alcohol and substance abuse; social workers, school nurses, parent-teacher committees and broader engagements with community organisations are not part of the system. Strike action (both official and unofficial) consumes around 10 days a year, approximately 5% of school time; union meetings during school time are the norm in schools located in townships; compounding this, procedures for dismissing teachers for misconduct are complex and time consuming and thus are rare. All these concerns require active participation and engagement of teachers, administrators, unions and parents and teachers and management need to be held accountable. Reforms implementing the testing of learners' numeracy and literacy, distribution of workbooks, simplification of work plans and introduction of teacher evaluation and a framework for development need to be encouraged and supported. The schools that have shown improved performance in poor communities have been found to have a good school principals who run the schools efficiently and in a disciplined manner, provide support for the teachers, provide mentorship for less experienced staff, take every opportunity to promote the schools in the broader community and get parents involved in their children's education (NPC, 2011).

The NPC (2011) is concerned with how young people can transition from school to post school learning and vocational training opportunities. There around one million young people who exit the schooling system each year, 65% of whom have not completed matric. Half of those who exit, do so post Grade 11, having either not enrolled in or failed Grade 12. Only a small number enrol in further education and training colleges or any form of post-school training; in 2011 there were only 115 000 enrolments in vocational training programmes. In general, there is poor growth in enrolments and poor throughput rates in the further education and training system. The NPC (2011) highlights the need for ways to support school leavers who do not directly qualify for direct entry into higher education. In higher education institutions, race remains the major determinant of graduation rates; in contact universities, the completion rate for black students is less than half that of white students – it is particularly bad for first generation students, only one in five graduate in regulation time. The difficulties faced by black and first generation students have major implications for social mobility and the effectiveness of the education system in creating an equitable skills base. Tertiary institutions have been transferred the problems generated in the schooling system; throughput rates are not keeping pace with enrolment and the demands for academic support from an increasing number of learners is not being coped with. The net effect is that the system can produce neither the number nor the quality of graduates required by the country (NPC, 2011).

Independent experts all agree that literacy and numeracy are major problems in South Africa, despite significant government spending, and that there is no easy or quick solution to the education crisis. Graeme Bloch (2011), highlights many of the same points that the NPC report does; low numbers of black students make it to, and even less through, matric and jobs and vocational training are lacking. Literacy and numeracy are the foundations on which the country needs to address poverty and inequality and get the high-level skills required for development and growth. Bloch (2011) highlights that good technical solutions with the curriculum and in schools themselves are not sufficient to address the situation; there is a need for united public pressure on what needs to be done moving forward, and what needs to be prioritised. Max Price, Vice-Chancellor of the University of Cape Town and Jonathan Clark, Director of the Schools Development Unit in the University of Cape Town's School of education (2011), highlight the poor performance of rural and township schools relative to many of South Africa's poorer neighbours as the principal concern. They do not discount the multitude of causes and societal factors that contributed to the failure of the public-school system, but believe that factors within the education system itself carry the most responsibility for the failure and in turn can have the biggest impact on improving the situation in future. Focus is placed on the following, which were also highlighted by the NPC (2011):

- Ongoing changes and amendments to curricula
- The availability of learning and teaching materials such as text- and workbooks
- Inadequate organisational support to teachers and the efficacy of the bureaucracy
- The balance of power between education departments, principals, teachers and unions
- Teacher efficacy

Colditz (2011), doesn't agree with the NPC's singling out poor black South Africans; the quality of education for most South African learners is substandard, and if left unabated will soon become true for all learners. Colditz (2011) is not surprised by the issues raised by the NPC, as these have been pointed out by various parties for years; he is concerned however by the lack of clarity on whether the situation can be fixed and how that can be achieved. Colditz (2011) states that teachers, school leaders and parents all have a role to play in solving the problem; as poor performance in literacy and numeracy can be blamed on the instruction that learners receive. Colditz (2011) also highlights two statements made in a Mickensey report (Barber & Mourshed, 2007):

- The quality of an education system cannot exceed the quality of its teachers
- The only way to improve outcomes is to improve instruction

Fleisch (2011), highlights the poor performance in Grade 6 language and mathematics Annual National Assessments as shown in Figure 22; only 15% and 19% of South African school children scored at or above the minimum proficiency in language and mathematics respectively. Focus is placed on exploring why South African school children are underachieving in key school subjects in primary school, thus leaving them ill prepared for secondary school and by extension life after school.

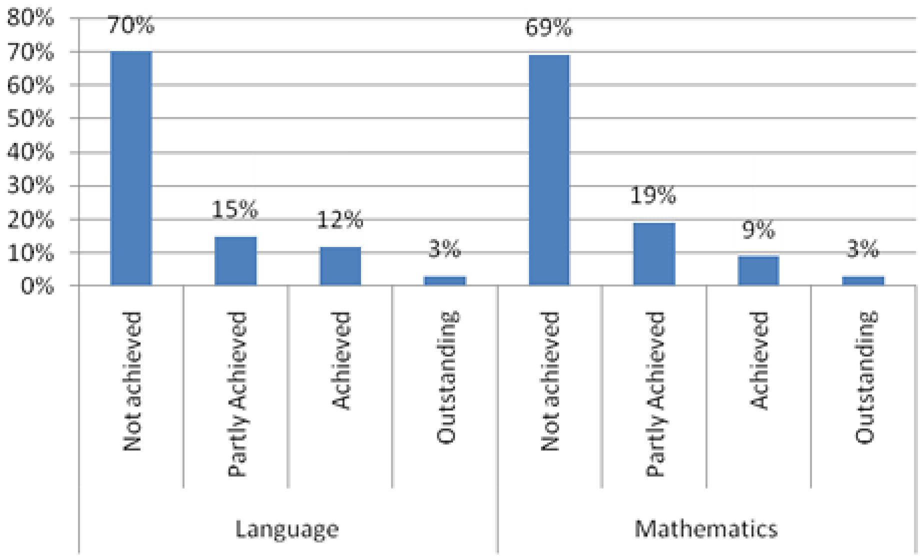


Figure 22: Performance in Grade 6 language and mathematics (NPC, 2011)

Fleisch (2011) agrees with the findings of the NPC – blame needs to be placed on apartheid while recognising that this is not the only cause. Social factors outside the classroom: including children's health, pervasive poverty, language practices; as well as factor within the classroom environment also have a significant impact.

3.1.3 Infrastructure

Infrastructure in South Africa is underinvested for what is needed to meet the countries social and economic needs. Unlike successful currency who invest and modernise public infrastructure based on economic, settlement and trade patterns, South Africa has fallen behind. There are complex hurdles standing in the way, the cost of modernisation needs to be balanced with a shifting production structure to suit the needs of a dynamic economy. South Africa needs to position itself to create a more labour-absorbing and knowledge-intensive economy while still expanding infrastructure to suit traditional activities such as mining. Geographically South Africa's position serves as a detriment, major trading partners in Asia, Europe and the Americas are separated from the country by large distances and the inadequate and poorly maintained infrastructure networks in Africa raise the costs of and hinder trade on the continent. South Africa needs a logistics system that is more efficient than would reasonably be expected, and to achieve this a political understanding for this need is critical; high levels of investment and institutional arrangements to bring in private money are required. There is the option of the state subsidising such a system, however this comes with the risk of inefficiency and rent-seeking instead of lower costs for the user. South Africa needs financial resources, political will and a commitment to reducing non-tariff barriers for infrastructure networks to run north to the growing continental markets. Within the country, it is necessary to recognise that while lines between resources mines and ports are important, the freight line between Johannesburg and Durban is probably more important (NPC, 2011).

South Africa also faces challenges in the energy and water sectors, in energy the nuclear question needs to be answered – weighing the pros and cons of a low carbon but expensive source of energy. Institutional arrangements to plan procurement of inputs in the most cost effective way are missing. An independent buyer would give Eskom certainty and create a fair basis to bring in independent producers. The 2010 Integrated Resource Plan has been a step in the right direction, balancing the need for energy supply and lower carbon emissions with the need for economic pricing. The 2nd edition of the National Water Resource Strategy would be an equivalent document for the water sector. Its delay is symptomatic of the problems faced in the water sector where knowledge on identified supply needs and management alternatives is often not translated into timely action (NPC, 2011).

South Africa has a low savings ratio, making capital relatively scarce. As such the country needs to be careful where investment is made; what is built and how it is built need to be carefully considered and all associated risks need to be examined. There is a need for coordination between the government and state-owned enterprises and sound and effective institutions are required to provide guidance through policy making and regulation to support financing, delivery and maintenance of infrastructure. The full picture needs to be looked at regarding infrastructure, incorporating all the people and systems involved in planning, designing, and building, maintaining and operating the complicated and expensive systems over a long period. Frameworks will be required to allow government and the private sector to collaborate. A regional perspective and regional initiatives are also important in tackling South Africa's challenges in managing water and ecosystems, reducing effects of climate change and developing infrastructure (NPC, 2011).

Independent experts do not agree that South Africa lacks enough appropriate infrastructure for its current level of development and even growth; they do however recognise that there may be boundaries and constraints that need to be overcome. Stephen Hosking (2011) believes that while the present infrastructure is not inappropriate, in there can be infrastructure inadequacies that are binding constraints on economic growth. Mr Hosking identifies electricity generation as one of the more obvious problem areas but recognise that the bigger challenge is to identify all infrastructure constraints and what parts of the economy they are holding back. Hosking (2011) does not see economic meaning in the term social inclusion but speculates to its possible relevance to under-subsidisation of utility services of some people, in which case it is more a challenge relating to the consequence of growth. Frik Landman (2011), does not believe that believe that knee-jerk solutions will help solve the problem. Landman (2011) recognises that it may emerge that existing infrastructure can take the country forward, but only by addressing boundaries, knowledge sharing, people and infrastructure in a more creative way. Only when a multi-functional design emerges will ‘how-to” offerings play a meaningful part in the solution.

3.1.4 Resource intensive growth path

South Arica’s early development like many colonial models was based on the abundance of natural resources that could be exploited for export while using very little for domestic consumption and development. However, because of its importance on trade routes and the established settler population, South Africa’s development included a more diversified domestic economy. Development was still funded by natural resource exploitation and was based on the exclusion of the indigenous people (NPC, 2011).

Today South Africa’s economy and society continues to reflect and reproduce the dependence on natural resource exploitation. The location of cities and people in the structure of the economy, and the continued social fragmentation and exclusion, including unemployment, poor education and low skill levels all reflect this. Natural resource exploitation makes the country vulnerable to external forces; the country’s economic booms and busts are often exacerbated by international commodity prices. The energy and transport demands of the minerals sector place heavy demands on economic infrastructure and the country’s energy-intensive, coal based economy will likely be penalised in future as the world seeks to fight climate change by lowering carbon emissions (NPC, 2011).

South Africa also faces challenges with the use of renewable resources on which society depends (NPC, 2011):

- Only 13% of the country is arable, only 3% has high agricultural potential
- There is little natural forest and only limited scope for plantation forestry
- South Africa is one of the driest countries in the world

Because of these factors, there is high competition for land and water usage. The intensity of water use in South Africa, 31% of available resource, is high by world standards and bay far the highest in the region; as intensity moves towards 40%, the country faces a binding water constraint. While South Africa has a whole still has a surplus of water, there are deficits in many regions resulting in the need for an extensive infrastructure network to store and transport water between and within river basins. The demands for water are expected to increase as communities and their economies develop, and living standards rise; it will become more difficult and expensive to meet domestic needs and supply water to both agriculture and industries. New infrastructure will be needed to increase supplies and to reuse more water; improved water resource management, protection from pollution and promotion of efficient municipal agricultural and industrial usage are also required. Implementation of any reforms will be challenging due to the diversity and complexity of the countries water resource and its use (NPC, 2011).

South Africa and the African region are particularly vulnerable to the impacts of climate change. In South Africa, parts of the country are expected to become dryer and the already high variability of rainfall may be aggravated. Climate change also poses a threat to South Africa's internationally recognised biodiversity, which supports an important tourism industry and has significant economic and social importance. Other threats include industrial, commercial and residential development, over-exploitation of resources and the impact of invasive species. South Africa needs to promote global action and help find and implement action plans for reducing carbon emissions. National action alone cannot address climate change, but is a step in the right direction. The country has committed to reducing emissions by 34% by 2020 and 42% by 2025 respectively; this commitment is dependent on financial, technological and capacity building support from developed countries (NPC, 2011).

The commitments to climate change present challenges for South Africa's fossil fuel dependent economy and for the design of a new and more appropriate development path. However, per the NPC (2011) the challenges faced by the current development path supply enough good reasons for seeking to build a new one. External forces increase the urgency for such a change; the rise of the BRIC (Brazil, Russia, India and China) economies boosts demand for minerals, but concerns about the price and availability of energy, most notably gas, as well as those over climate change are driving major technological transformations, which create both threats and opportunities for South Africa. The price of food is also growing, because of growing global population, rising living standards and the increasing use of agricultural products to produce energy. The new development path needs to be more inclusive, less dependent on the exploitation of non-renewable resources and use renewable resources sustainably and strategically (NPC, 2011).

The NPC (2011) recognises that in the medium-term, agriculture, while not contributing as significantly as other sectors to the economy, provides many of the low-skilled jobs that are needed and provides price stability and security in food supply; sustaining production while sharing the benefits more broadly will be challenging. Formalised proposals for investment in electricity generation highlight a broader development challenge; as the system is transformed, new job creation opportunities will arise, however more expensive energy will constrain activities and potentially lead to job losses in the mining industry. The mining industry creates many low-skilled jobs and helps fund imports, including inputs required for development of new industrial sectors) through exports of raw materials. These gains and losses need to be weighed, and government and industry need to look at innovative ways to support and transform this sector as the country proceeds to a low carbon future. The potential benefits from further development of natural resources and mineral endowments need to be balanced with a less energy intensive development path that is more environmentally sustainable and offers more opportunities for marginalised sections of the population. This is a critical future challenge for the NPC, costs of such a transition will not fall evenly on the population; export sectors will suffer because their dependence on intense resource exploitation. Poorer households, living in poorly insulated and badly located housing will also suffer (NPC, 2011).

NPC (2011) highlights that the following questions need to be answered:

- Is it possible to reduce carbon emissions and environmental impacts and remain a competitive commodity exporter?
- How quickly can the economy shift from being a high resource-intensive one to a more knowledge-intensive or labour-intensive one?
- How does the country balance the need for infrastructure to suit today’s economy, without locking in the present resource-intensive development path?

Independent experts do not agree with the premise of the NPC report that South Africa is over exploiting its resources and that dependence on these makes economic growth unsustainable. John Powell (2011), doesn’t see how the dependence of South Africa upon high resource levels makes the countries growth unsustainable. Powell (2011) recognises that in the sustainability and lowering carbon emissions are areas that need to be addressed, but cautions against perusing them too quickly. Powell (2011) believes the real sustainability crisis in South Africa is not centred on exploitation of resources, but rather around the growth of knowledge; the country needs to exploit its current favourable resource position to fund a more sustainable knowledge position in the future. Stephen Hosking (2011a) does not believe that that South Africa’s current growth is based on excessive exploitation; exploiting the comparative advantage the country finds itself in is a predictable outcome. Hosking (2011a) believes that South Africa’s real challenge is for government to make sure that broader economic and not only financial costing is employed to guide the private sector to social optimums in resource input use and exploitation.

3.1.5 Spatial challenges

In South African cities, the poorest live the furthest from places of work and economic activity. This was a primary focus even before 1994, however the situation for the poor has been aggravated not lessened since, with many more people now living in poorly located settlements. This spatial divide adds to challenges of providing infrastructure in support of economic activity and reversing the effects of this trend will be an ongoing problem for decades (NPC, 2011).

In urban areas, different spheres of government are responsible for delivering different parts of household infrastructure as part of the broader process of building vibrant and viable human settlements (NPC, 2011):

- Municipal (local) government is responsible for planning and delivering water, electricity, sanitation and refuse removal.
- Provincial government delivers housing, schools and clinics.
- National delivers protection services, bulk services and part of the transport network.

This fragmentation results in coordination failures, inefficiencies and slow service delivery and is a fundamental concern. One solution is to shift the housing function to municipalities to help align it with municipal services, and this is already under way in certain areas (NPC, 2011).

In general, the NPC (2011) believes that solution does not lie in complete centralisation or decentralisation, but in ensuring that national and provincial government's sectoral infrastructure initiatives are aligned with municipal plans. This can be achieved by strengthening the planning responsibilities of municipal government and creating a stronger and more coherent planning framework, which requires concrete efforts from national and provincial government to address and support the significant challenges to creating effective plans. Even with this in place, no easy solution for the challenge of spatial marginalisation exists. In cities settlement patterns are largely driven by land costs and government needs to find a way to help people access better located land. A reliable and affordable public transport network is also needed to allow poor people to participate in the life of towns and cities. Questions on whether it is feasible to provide a network given the great distances and low population densities involved; or whether it is viable to move economic activity and opportunities closer to poorer communities. In rural areas, the challenges are even greater, raising difficult issues and trade-offs. A more comprehensive view of the rural development landscape is already being undertaken by present policy, focusing on: incomes, employment opportunities, enterprise development and existing programmes of infrastructure and land reform. It also needs to be decided what services to provide, how and where these should be provided, and the level of service delivery; even basic municipal services are costly to build and operate in rural areas (NPC, 2011).

There is considerable mobility within rural areas, expansion and densification of rural informal settlements, and processes of rural-urban migration. An emerging trend is for “rural” populations to concentrate along transport corridors. The following questions, highlighted by the NPC (2011) need to be addressed:

- What infrastructure could improve basic livelihoods by enhancing the economic potential of rural areas?
- Should basic household infrastructure be combined with roads, access to water and irrigation services, improved extension services and complementary social infrastructure to support agriculture or should it rather focus on the emerging "corridors of opportunity"?

To answer these the NPC (2011) identifies that a coherent vision of the role of agriculture is required. Based on experience of other countries, the agricultural sector in South Africa has the potential to provide substantial livelihoods for more people than it currently does and it needs to be determined whether the country has the capacity, will and desire to do this; or whether the "agricultural transition" leading to dramatic shrinkage in the number of people engaged in agriculture, as observed in other countries, has already taken place.

3.1.6 Public health

Over the decade leading up to 2008, the total number deaths in South Africa has increased sharply. The rise in the number, along with an increased prevalence of HIV/Aids and tuberculosis, lowering life expectancy and increasing infant mortality rates, points to a healthcare system that is in distress. These trends are shown in Figure 23.

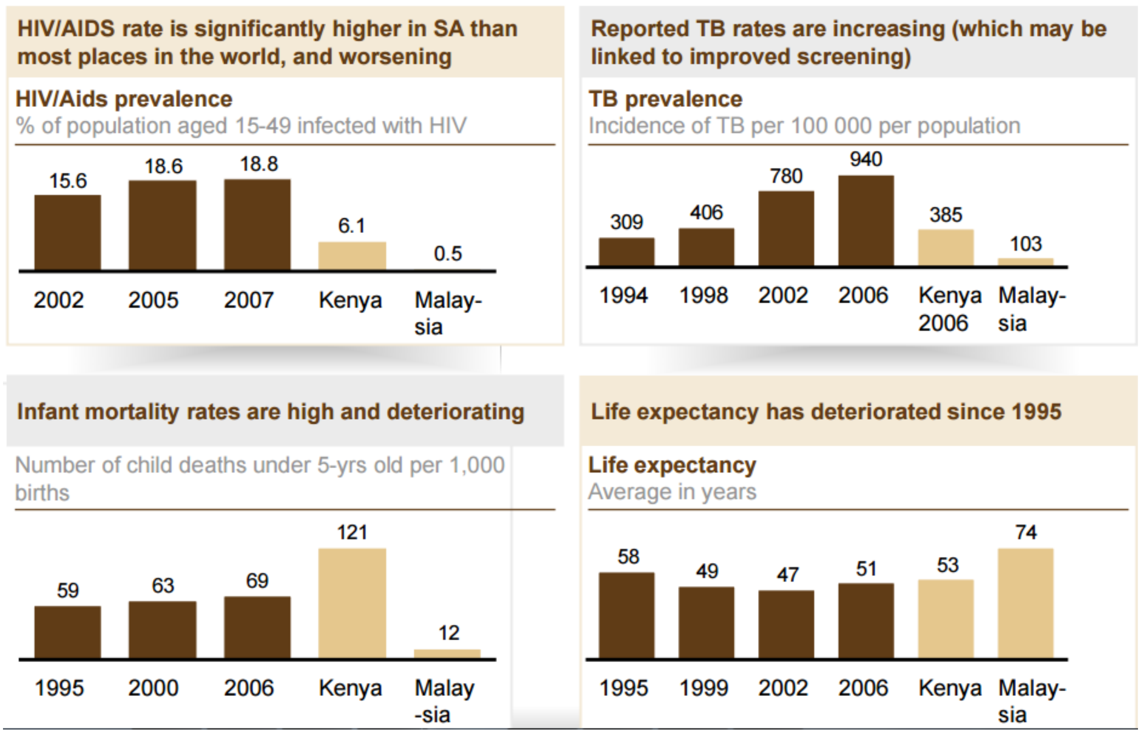


Figure 23: Significant healthcare indicators highlighting deteriorating performance in South Africa (NPC, 2011a)

The NPC (2011) highlights that South Africa has a quadruple disease burden, and it's sore on the United Nations Human Development Index reflects the impact of this burden on all aspects of society. South Africa's four disease burdens are defined by the NPC (2011) as follows:

- The HIV pandemic, South Africa has 0.6% of the world's population but a staggering 17% of the world's HIV infections.
- The high incidence of injury, both accidental and non-accidental. There is a high rate of trauma cases resulting from violence and road accidents; the injury death rate per population stands at 158 per 100 000 – nearly twice the global average.
- Infectious diseases such as tuberculosis (11% of the world's cases), diarrhoea and pneumonia; these interact in negative feedback loops with HIV and malnutrition and have a significant impact on infant and maternal mortality rates. Infant mortality stands at 43 per 1000 live births and maternal mortality at 625 per 100 000 live births.
- The growing epidemic of lifestyle (non-communicable) diseases related to relative affluence. Disease such as diabetes and heart disease are rising sharply, there fivefold increase by 2004 relative to the baseline value in 1997.

In all areas, South Africa's rates exceed global averages, often by a significant margin; and while many of these epidemics are not new, the evolution of diseases such as HIV have completely changed the nature of the disease burden in the country. On top of these South Africa has the world's highest rate of incidence of foetal alcohol syndrome. AIDS-related deaths have dramatically increased in young adults, and more so in young woman. In 20 to 39 year olds there has been a marked change in whether men or woman are more likely to die; in 1997 men were 1.6 times more likely, while by 2007 this has shifted to men being 1.05 times less likely to die. Per the NPC (2011), it is likely that all the increase in deaths from communicable, as well a considerable part of those classified as non-communicable, can be attributed to AIDS and HIV-related tuberculosis.

The NPC (2011) recognises that in tandem with this rise in South Africa's disease burden sits the decline of the country's health system. While this can partly be attributed the nature of the disease burden, there are also institutional issues and implementation failures that have occurred over a long period. Government has not adapted to the evolving disease burden and not dealt effectively with the required policy and implementation reforms. The NPC (2011) highlights several mistakes that serve as evidence of these failures; first among these are errors in the management of human resources in the healthcare sector – these include over-centralisation of basic institution level functions, and a correct but poorly implemented strategy shifting the patient burden to primary healthcare facilities. The state has built 700 new clinics since 1994 to shift the sector toward preventative modes instead of curative and relieving hospitals of patient loads. In a well-functioning primary healthcare system, earlier diagnosis and treatment should result in better health outcomes, however the reality in South Africa is that the quality of primary healthcare is unsatisfactory and clinics often run out of medicines. Couple this with patients reframing from using these clinics due to public perception of the standard of primary healthcare, and lower patient loads in the hospital system and better health outcomes are not attainable. Another area of policy lapse, and per the NPC (2011) the most severe, relates particularly to the treatment of professional staff in public healthcare. The status and role of these professionals is undermined by the rise of silo-based management systems with erode discipline and management authority. The training capacity for all levels of healthcare professional was also reduced and thus there is a massive shortage of skilled staff in the sector. Response to personnel related challenges have been ad hoc and often inappropriate despite recognition of the problem by policy makers (NPC, 2011).

The steady collapse of the public healthcare has prompted a portion of the population to turn to the private sector. A quarter of South Africans periodically use some form of private healthcare, and 17% are cover by private medical insurance – which comes at significant costs. While it only covers a small portion of the population private healthcare accounts for almost 5% of GDP. Given its high cost it is concerning that the quality is variable and there is a significant over-reliance on hospital care and strong evidence of over-servicing. The private sector is not only competing with public healthcare for patients, but also for skilled personnel; remuneration for doctors and specialists is significantly higher in the private sector, however remuneration for nurses is lower. Many doctors and nurses are discouraged from joining the public sector due to heavy workloads and demanding conditions; the private sector claims to discourage doctors and nurses from working overseas and argues that it plays a role in training nursing staff (NPC, 2011).

While competition over skilled staff is a concern, it cannot explain the poor quality of public healthcare and the poor health outcomes within the general population. The NPC (2011) highlights that efforts aimed at improving health outcomes are focused on two broad areas:

- Improving the quality of public healthcare
- Introducing a national health insurance model

It also highlights several determinants on which improvements depend:

- Stabilising and reducing new HIV and TB infections, while also treating those already infected
- Promoting healthier diets and exercise, and a change in lifestyle to limit the HIV spread

- Reducing levels of domestic and violent crime, and reducing the number road accidents
- Improving nutrition levels and micronutrient intake, especially among children.
- Improving water quality and access to proper sanitation
- Improving the quality of primary healthcare, for pregnant women and very young children
- Raising the number of people trained throughout the health system, and ensuring they are retained in South Africa

Looking at resources expenditure, public health accounts to 3.5% of GDP, which is equal to most other middle-income countries. These countries do not share South Africa's significant disease burden, and therefore it can be argued that increased spending is required. It is not clear whether the financing model itself needs amending; in the 2005/2006 fiscal year 40% of healthcare financing came from general taxation, 45% from medical aid contributions and 14% from out of pocket payments. South Africa's health financing can be considered progressive, even though healthcare access and outcomes are not. Where funding in public healthcare is progressive, funding in private healthcare is regressive; the poorest 20% contribute a significantly higher proportion of their income than the richest 20%. The distribution of benefits however is still skewed in favour of the wealthier portion of the population who make use of private healthcare, and who also bear lower disease burdens; funding per patient is significantly higher in private healthcare, with medical aids spending approximately five times as much per person as the public sector spends per uninsured person (NPC, 2011).

There is a need for reforms to narrow the gap in quality between public and private healthcare by linking the sectors more closely; this will enable more choice for more people and jointly raise the quantities of people trained in healthcare professions. One area for that could benefit from increased collaboration and raise standards for minimal extra cost is hospital management. There is also a need for policies aimed at reducing the cost of private healthcare over time, which would have broader social benefits (NPC, 2011).

Independent experts agree that addressing the healthcare problem in South Africa will require greater integration and coordination of both the public and private health sectors and that healthcare practitioners play a central role. Jonathan Broomberg (2011), highlights that South Africa's challenges in the health system are not separate from the other challenges outlined by the NPC and therefore solving healthcare requires solving broader issues. Broomberg (2011) does however lay out suggestions for reforms in both public and private healthcare, as he believes that solution lies in addressing both systems to generate an integrated national health system that can provide a solid foundation for the future. Public sector reforms highlighted include: additional human resources, improvement of cost-effective management of chronic conditions, improvement of systems and management, and additional funding; private sector reforms highlighted include: regulation of medical schemes so that they contribute to national health objectives, improvement of provider side regulation and incentives, and improved tax regulation. Anton Stolz and Gustav Wolvaardt (2011), believe that health indicators such as life expectancy are a barometer of progress in a country. Stolz & Wolvaardt (2011) believe that addressing the ailing healthcare system will translate into an improved ability to respond to emerging and re-emerging infectious diseases. Key factors to improving the healthcare system include:

- Creating greater integration between public and private healthcare
- Professionalising healthcare and management in the public sector
- Harmonising treatment regimes in both public and private healthcare
- Establishing a functional national health information system
- Ensuring the country has sufficient healthcare professionals
- Quality control for the quality of health care provided in both public and private healthcare

Norman Faull (2011), believes that the solution lies in adapting the philosophy of lean thinking; observing a situation to understand what is value adding, what isn't, why challenges and bottlenecks occur is useful to identify simple steps that may lead to improvements. Mr Faull cites examples of where lean thinking was applied to several hospitals and resulted in marked improvements. Jason Myhill (2011), believes there is a constant tension between the critical needs of the healthcare service and economics, placing healthcare practitioners under immense pressure when economic conditions are unfavourable. Myhill (2011) believes that understanding the predictability and impact of several key uncertainties is key to understanding which ones can be planned for and therefore managed. Key uncertainties that private and public healthcare services in all countries are subject to include:

- Medical inflation
- Skills and talent
- Epidemics
- Consumer behaviour
- Technology
- Corruption
- Equitable affordability

In South Africa's case the lack of healthcare skills and talent as well as the ever-increasing advancement of lifestyle epidemics like HIV/Aids are having a deep and lasting effect on healthcare.

3.1.7 The National Development Plan 2030

The NDP 2030 is the document outlining South Africa's path forward. This section dealt extensively with the NPC diagnostics report on which the NDP 2030 was based and therefore covers all relevant material on the direction the government aims to take the country. The next section will deal with the BGE 2015 report, which provides a useful follow up on what progress has been made. It is therefore not necessary to explore the plan in more detail.

3.2 Key problems that need addressing

In May 2015, The Boston Consulting Group (BCG) released a report about four key problems that require leadership at all levels in South Africa (Ikdal et al., 2015) to translate national wealth into the well-being of citizens and to ensure sustained economic growth which has slowed in recent years. This subsection focuses on the findings and recommendations of the BCG report. The four critical areas, identified by BCG (Ikdal et al., 2015) are (these will be covered individually later in this section as in the BCG report):

- Education
- Healthcare
- Unemployment
- Income inequality

BCG has developed a methodology, the Sustainable Economic Development Assessment (SEDA) described in Figure 24, to measure how effectively a nation converts wealth into the well-being of citizens. Ten key dimensions are examined in terms of current level and the countries improvement (recent progress) and measured on a scale from 0 to 100. Two coefficients are calculated using the current level and recent progress SEDA scores to examine the relationship between a countries wealth and the current well-being of its citizens, and the relationship between growth and recent progress in well-being. In either case countries with a coefficient greater than 1.0 are delivering well-being and improvement in well-being at level higher than expected for their per capita GDP (Ikdal et al., 2015).

Using this methodology, the BCG (Ikdal et al., 2015) ranks South Africa 138th out of 149 countries. Figure 25 taken from this report shows a comparison between a country's per capita GDP and its current SEDA score and assigns the wealth to well-being coefficient. The figure shows multiple countries' positions; however, its purpose is to highlight South Africa's position and it is therefore the only one identified. As seen in the figure, South Africa sits at the bottom end with a wealth to well-being coefficient of 0.5.

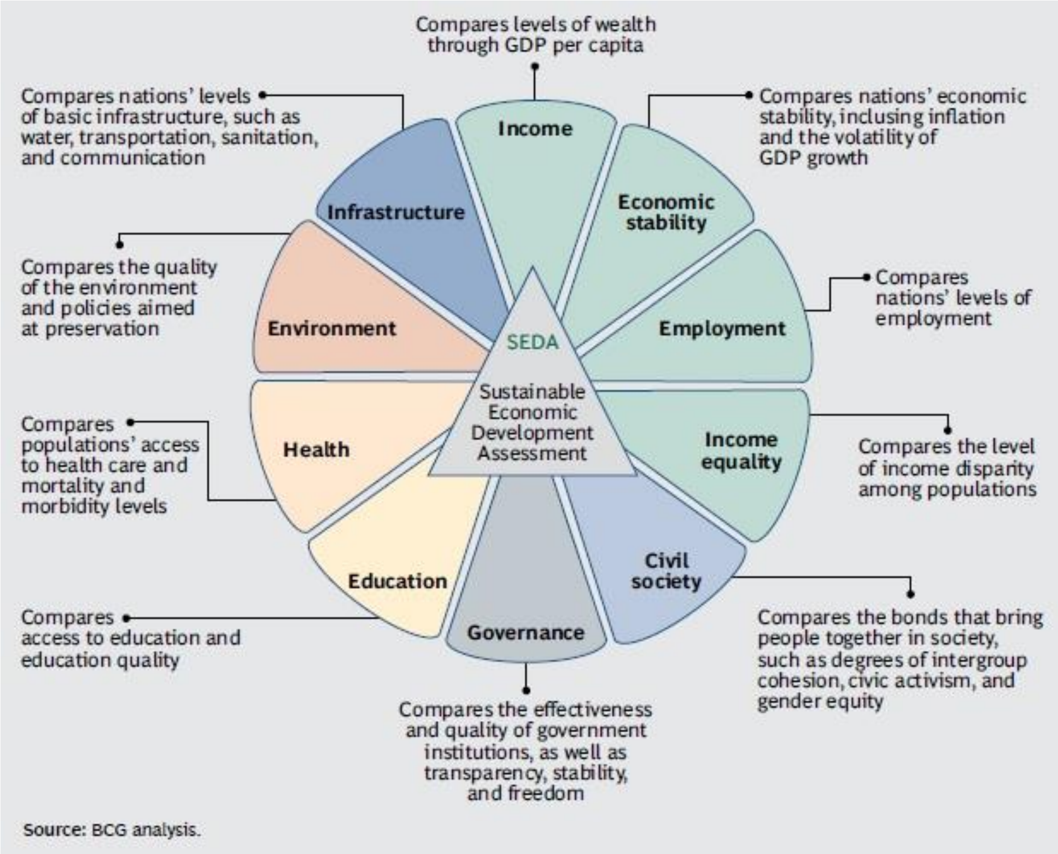


Figure 24: SEDA (Ikdal et al., 2015)

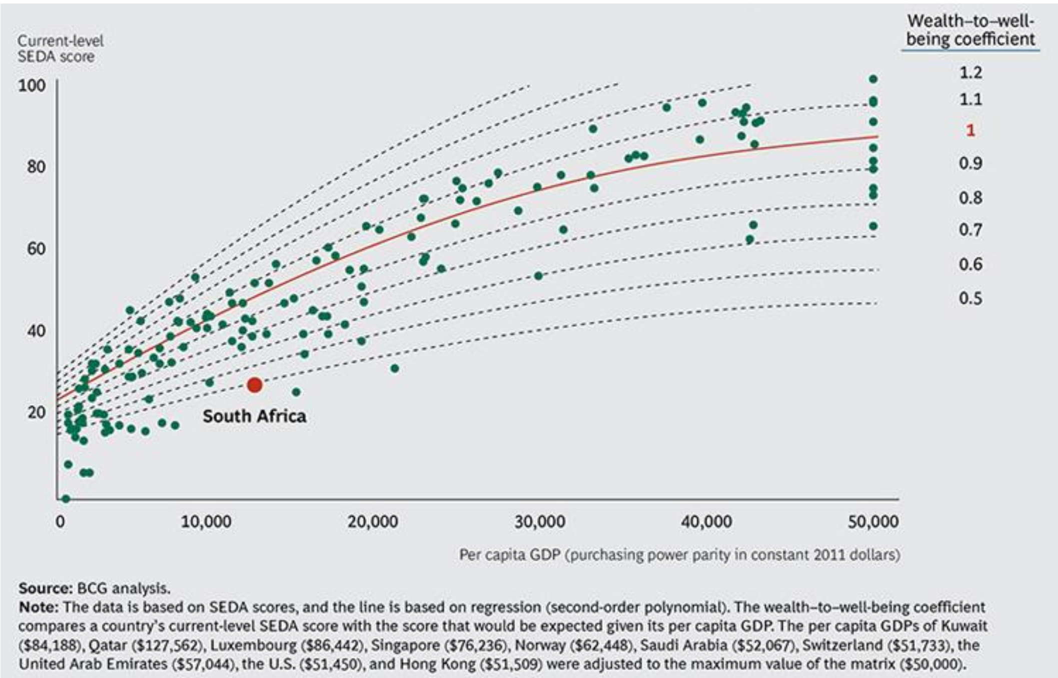


Figure 25: Per capita GDP vs current-level SEDA score highlighting South Africa's position (Ikdal et al., 2015)

The BCG analyses the data further by comparing countries with peer groups consisting of other countries chosen based on similar size, economic and social characteristics. This sort of analysis exposes areas of lagging performance and highlights areas where high-impact solutions can lead to outsize improvement in standing (Ikdal et al., 2015). In Figure 26 South Africa was compared to three peer groups of neighbours and countries with a similar global standing (Ikdal et al., 2015):

- Sub-Saharan challengers

Consisting of ten emerging economies from the region, sharing several characteristics – GDP per capita of more than $2,000, population of more than two million and a democratic government.

Specifically, this group consists of Angola, Botswana, Cameroon, Cote d'Ivoire, Ghana, Kenya, Namibia, Nigeria, Senegal and Zambia. The average per capita GDP of the group is $5,413, with the average real GDP sitting at $38 million, and an average population of 34 million.

- Global peers

Consisting of eight countries at a similar level of development to South Africa, with per capita GDPs ranging from 75% to 125% of South Africa's and populations ranging from 15 to 250 million, to South Africa's 53 million.

Specifically, this group consists of Algeria, Colombia, Ecuador, Egypt, Indonesia, Peru, Sri Lanka and Thailand. The average per capita GDP of the group is $11,217, with the average real GDP sitting at $172 billion, and an average population of 69 million.

- Advanced peers

Consisting of six global economies that exceed South Africa and have had consistent growth over the past two decades translating into increased well-being for their citizens. They have a per capita GDP ranging between 125% and 200% that of South Africa and a recent growth rate exceeding 60% over 20 years. The populations of these countries range from 15 to 250 million and they all have high SEDA wealth-to-well-being coefficients.

Specifically, this group consists of Chile, Brazil, Malaysia, Poland, Romania and Turkey. Brazil has been included in this group, even though its per capita GDP places it among the global peers.

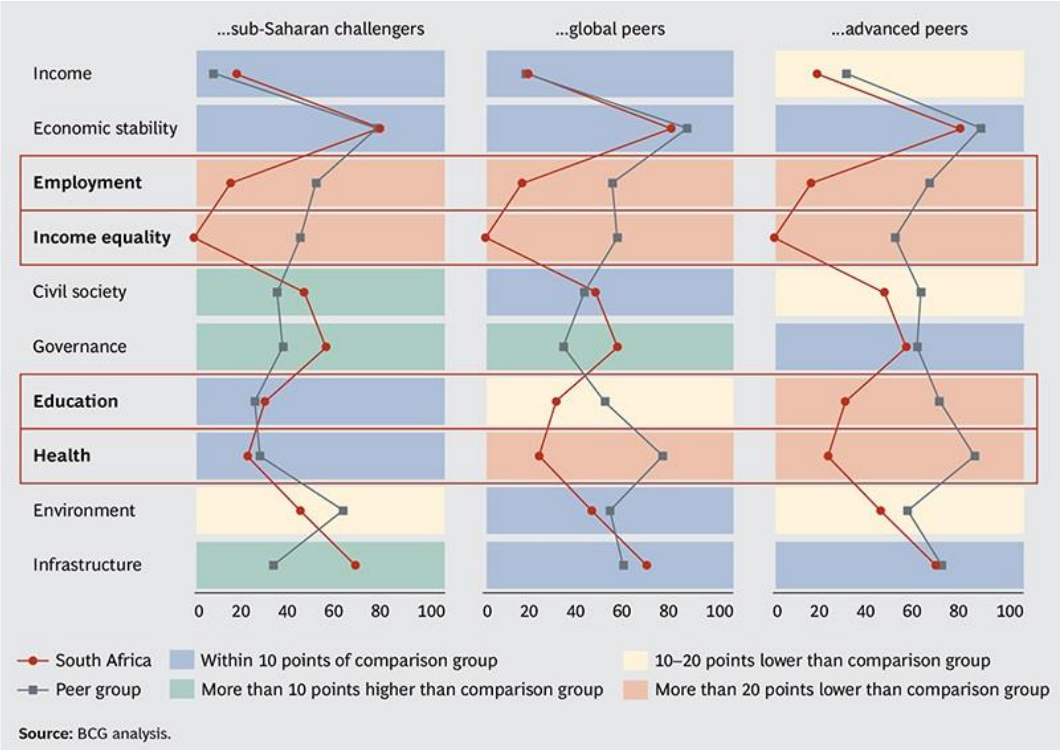


Figure 26: Comparing South Africa to neighbours and peers (Ikdal et al., 2015)

The figure shows that in terms of income, economic stability, civil society, governance, environment and infrastructure; South Africa is mostly on par, and in certain cases ahead of its peers. However, the four critical areas mentioned earlier – employment, income equality, education and health – are clearly the areas where South Africa is lagging. While education and healthcare are a problem shared with the peer group of sub-Saharan challengers, employment and income equality are areas where South Africa lags all nations of similar global standing.

The BCG (Ikdal et al., 2015) identifies that these four areas are part of an unfortunate cycle impeding the country's ability to improve its economic and social well-being. Poor education and training leads to a lack of skills, contributing to high unemployment. This in turn fosters income inequality and slows economic growth, limiting access to funding for education and healthcare. The way forward requires careful consideration and planning on how to apply resources, as stated by BCG (Ikdal et al., 2015) improving education is essential for breaking the circle in the long term, however to improve well-being in the short term – improvement in healthcare, unemployment and income inequality is required.

3.2.1 Education

The assumption is often made that poor performance in an area can be attributed to not investing enough funding into it. This however is not the case with Education in South Africa, in Figure 27 taken from BCG (Ikdal et al., 2015) we see that South Africa already spends more per capita on education then many of its peers. We also see that South Africa ranks last of its peers in terms of quality of education, far below the peer group and global averages. Instead of excessive spending setting the right priorities, focusing on the right areas can yield significant short and long term gains as demonstrated by peer nations.

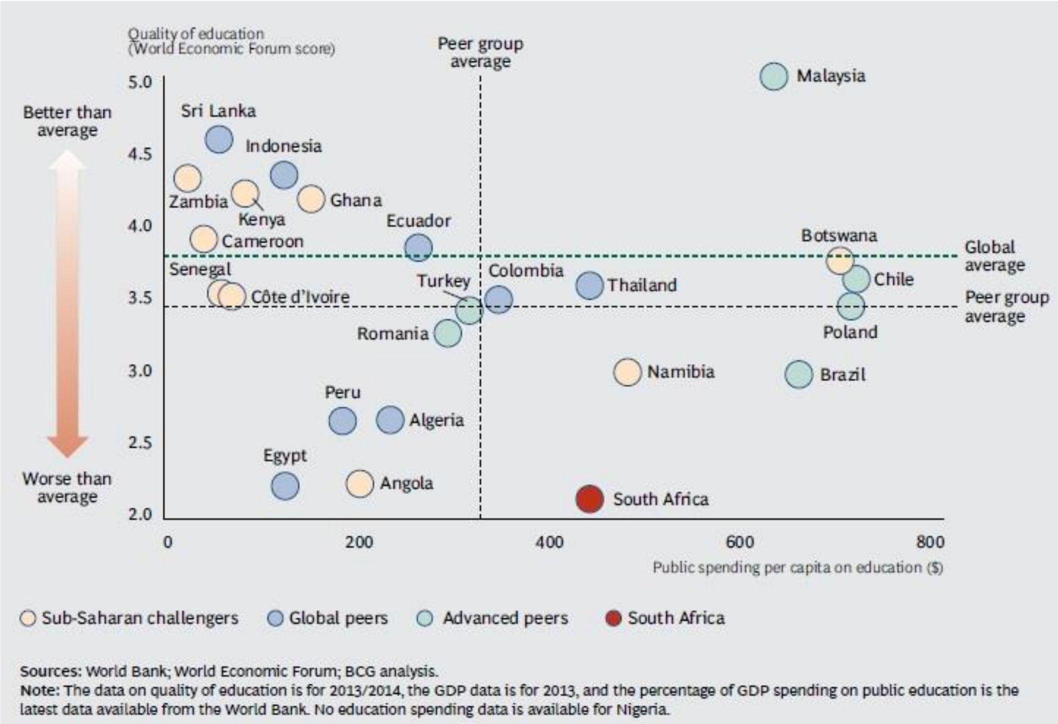


Figure 27: Public spending per capita vs quality of education (Ikdal et al., 2015)

BCG (Ikdal et al., 2015) identifies four critical issues that need to be addressed and highlights examples of poor performance in these areas:

- Teacher quality

Studies have shown that 60% of mathematics teachers for grades one through six failed to pass a maths test designed for the grade level they were teaching.

- Basic skills

Students perform poorly in math, science and reading. Only 35% of sixth graders are acceptably numerate, with the amount dropping to 3% by ninth grade. South Africa ranks last (144 out of 144) in terms of quality of math and science education per the World Economic Forum's Global Information Technology report 2014. In the 2014 South African Annual National Assessment, 48% of ninth graders scored 50% or higher in "home language" literacy and only 18% scored 50% or higher for their first additional language.

- Dropout rates

High dropout rates inhibit skill building and limit employment opportunity. Per the Department of Basic Education's 2014 Country Progress Report, 86% if 16 to 18 year olds are in school but only 5% complete grade 12 by the age of 18. Research also shows that students completing grade 10 have a 52% chance of employment, grade 12 a 67% chance and that tertiary education raises the chances dramatically. Completing one additional year of tertiary education improves the chance of employment to 86%.

- Vocational training and higher education

The lack of vocational and practical skills compounds the problem caused by high dropout rates. This problem should be combatted by Further Education and Training (FET) colleges; however, these are not numerous enough and do not enrol enough students annually to compensate. The problem is intensified as many of these colleges do not provide practical, hands on skill building, instead focusing on theoretical training making them both less attractive and less useful. There is also a lack of collaboration with prospective employers leading to a lack of training in market-relevant skills.

These issues are not new and are addressed by both the latest education reform programs and the National Development Plan – which will be discussed in the following sections. There are numerous initiatives and policies in place to improve education and address these issues. The BCG (Ikdal et al., 2015) believes that focusing on four key priorities will heighten the impact of reform:

- Achieving a mind-set shift

A quote by Taddy Blecher, sums up the need for the correct mind-set – "Infrastructure is not as important as the mind-set. If the mind-set is right, people can achieve anything, even by learning under a tree." Leadership is required, both from government officials and role models in various areas of society, to recognise the important role that education and the people who deliver it play, and the country needs to remember what Nelson Mandela once said – "Education is the most important weapon which you can use to change the world" (Ikdal et al., 2015).

- Making teaching quality measurable

The quality of teachers directly translates into the performance of students, good teachers are therefore a critical part of turning the educational system around. Examples exist of poorly resourced schools in some of South Africa's poorest communities achieving matric pass rates, at a university qualifying level, of more than 90% due to the quality and commitment of teachers. There exists no systematic means of measuring performance of teachers; therefore, no way to reward good performers, and identify and make improvements to underperformers. The absence of a system is partly down to the strong roll that the teachers' union plays; unions do not allow teacher evaluations and do not allow teachers to remain after hours to participate in training. Despite this, teachers and the department of education do have common goals regarding student performance and teachers' reputation. It is up to the government to facilitate dialogue among all stakeholders (teachers, unions, school administrators, students and parents) to put a performance management system in place and create accountability among teachers and principals. Evaluating and supporting teachers has had great impacts, demonstrated by results in the Programme for International Student Assessment (PISA), in the country of Japan and the city of Shanghai (Ikdal et al., 2015).

- Strengthening vocational training opportunities

Azar Jammine, chief economist at the South Africa consultancy Econometrix, states – "We need a tiered education to ensure that learners who are less comfortable with the theoretical knowledge can exit our education system with a strong skill set under their belts. It is only through education that we will achieve long-term transformation and growth in our economy." Introducing a tiered education system, funded by the government, that includes a clear route that students could potentially follow from grade nine into vocational training geared to both the students' talents and the needs of the economy could have positive impact on reducing youth unemployment and strengthen the economy. Germany provides students the chance to enter vocational school at the age of 16, where students receive both theoretical and practical training in vocations based on the market demand for given skills. This has undoubtedly contributed to the country reducing youth unemployment form 15.6% in 2004 to 7.2% in February 2015 (Ikdal et al., 2015).

- Reducing dropout rates

Addressing the dropout rate can quickly have a significant impact on the employability of youths entering the workforce. Research shows that the three main reasons that 60% of men leave school early are lack of funds, poor academic performance and not seeing the value in continuing, while the three main reasons that 62% of women leave early are also, lack of funds and poor academic performance and additionally family commitments. It is necessary for leaders to emphasise the link between education and employment, highlighting the importance of math and science for many career options but especially reading, students need to be made to understand that finishing some form of education is critical for their futures. The government can also help reduce dropout rates by addressing the students' lack of funds, financial incentives such as conditional grants based on attendance and performance, can be offered to low income families to keep youths in school (Ikdal et al., 2015).

3.2.2 Healthcare

Since the early 1990s South Africa has faced a serious problem with HIV/Aids, which contributed to a sharp decline in life expectancy. Per the BCG (Ikdal et al., 2015) the scenario has been improving in recent years, life expectancy of South Africans has risen by 9% since 2005 and HIV incidence has dropped by 55% since 1999. However, the country is still lagging its peers in dealing with HIV/Aids and while life expectancy is moderately higher than its sub-Saharan challengers, it is still significantly lower than global peers.

The BCG (Ikdal et al., 2015) states that HIV/Aids remains one of the leading causes of death for adults in South Africa, factoring in on around one-third deaths. It is not itself a killer but its effects on the immune-system opens the door to tuberculosis (TB), influenza and pneumonia. Figure 28 from the BCG (Ikdal et al., 2015) shows the trends in life expectancy, HIV prevalence and HIV incidence in South Africa and its peer groups. From the figure, while South Africa is far behind its peer groups, it is on the right track in dealing with the epidemic. Stavros Nicolaou (Ikdal et al., 2015)., agrees that the country is the right track stating – “The South African government has made tremendous progress in slowing down HIV infection rates and, in some cases, reversing infection trends.” The improvement can be partly attributed to better education on the subject, better prevention and the availability of improved antiretroviral treatments, improving the life expectancy by four years since 2007 per the BCG (Ikdal et al., 2015).

South Africa has often exceeded World Health Organisation (WHO) recommendations with a progressive approach to HIV and TB treatments (Ikdal et al., 2015). The BCG report cites examples of the country implementing the WHO-endorsed Xpert MTB/RIF testing methodology for TB, being the only country to conduct the HVTN 100 trial to assess a new HIV vaccine in 2015, and beginning a trial on the use of microbicides to prevent HIV transmission in 2011 and another to treat patients with multidrug-resistant TB in 2014. The government has invested heavily in prevention, providing education on the use of condoms and making them available at no charge.

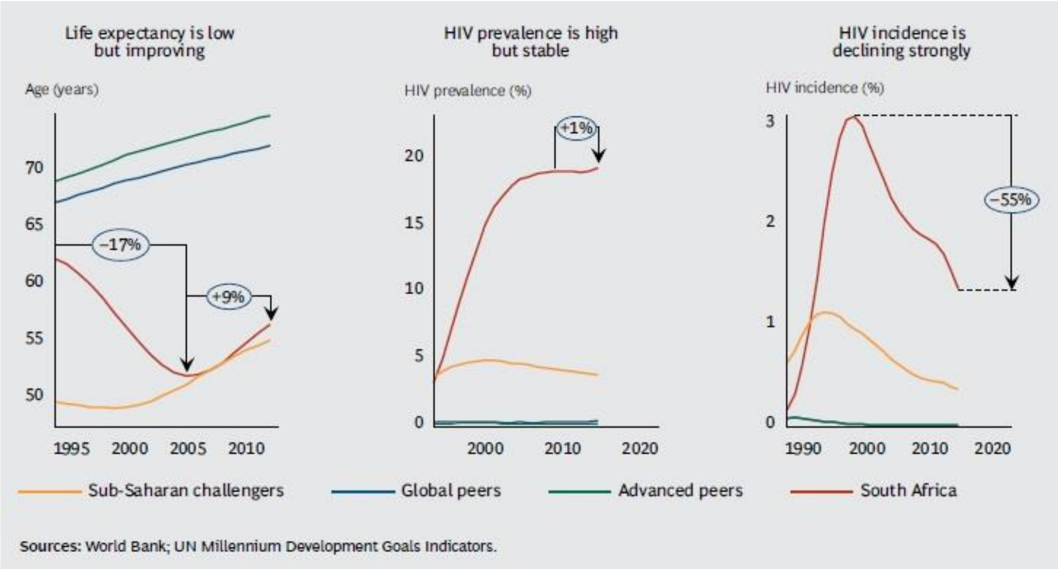


Figure 28: Progress in addressing HIV/Aids (Ikdal et al., 2015)

While HIV/Aids is attributed with being the leading cause of death in adults, the BCG (2015) states that the main causes of death among South Africa children younger than five are related to poor hygiene and infectious diseases, also accounting for around one third of deaths. Compounding the problem are the low immunisation rates in South Africa, lowest among all the country's peers in immunisations for measles and diphtheria. While the low immunisation rates don't directly lead to many deaths, they are a factor and leave the country open to a major epidemic. The BCG (Ikdal et al., 2015) recommends that the country focuses on child mortality in the same way it has been addressing HIV/Aids, focusing not only on treatment but on prevention, the access to clean water and proper nutrition are still problem areas despite recent improvements – access to potable water has increased from 60% in 1994 to 96% in 2012 (Ikdal et al., 2015).

The BCG (Ikdal et al., 2015) identifies key focus areas to help in South Africa's fight against HIV/Aids and other infectious diseases, child mortality and to improve general healthcare:

- Primary health-care facilities in rural areas

A key issue in the ongoing war with HIV/Aids is the lack of integration of primary healthcare facilities in rural communities. This limits the chance to diagnose and treat ailments in their early stages, and undermines the country's integrated prevention, testing and treatment approach to reducing the spread of infection of HIV and TB (Ikdal et al., 2015).

- Targeted health services

More focus must be placed on preventing infection in high-risk groups, for example combating HIV incidence in teenage girls. Further examples include preventing infection with TB for people already infected with HIV, and ensuring distribution of antiretroviral drugs to HIV sufferers. This can be achieved by providing access to targeted healthcare and education, particularly in rural areas (Ikdal et al., 2015).

- Improving maternal care

South Africa needs to increase the number of healthcare workers able to provide maternal care and improve their training. The country can learn from the model applied in Ethiopia – young women are trained as health extension workers (HEWs) and provide various basic healthcare services such as education and health promotion, testing and screening and select clinical interventions. These HEWs help to reach about 90% of communities throughout this mostly rural country (83% of the population lives in rural areas). Former South African deputy president, Phumzile Mlambo-Ngcuka, believes that we have good healthcare infrastructure, but many pregnant woman do not understand the need for check-ups, stating that “more public education is required to encourage women to use medical facilities” (Ikdal et al., 2015).

- Facilitating the roll of community health workers

Community health workers provide various key healthcare services, however there is so standardised approach to training them, nor a common mandate for their roll. There needs to be a clearly defined approach (guided by the healthcare priorities of the country) and a standardised system for the collection of clinical health data for community health workers to effectively do their duties. The Institute for Healthcare Improvement and the University of KwaZulu Natal launched a pilot programme for a systematic and data-driven approach to identifying gaps in local healthcare and providing targeted training to community health workers. It was found that community members treated by these health workers were more knowledgeable about their ailments and had more confidence in the treatment they received (Ikdal et al., 2015).

- Improving immunisation

More effort needs to be put into spreading awareness and educating people about vaccinations. The country provides free vaccinations however there is a problem with reaching those that really need it. Community health workers are essential in this regard, particularly in remote areas, and should be trained to communicate the importance of vaccinations and to administer them (Ikdal et al., 2015).

3.2.3 Unemployment

Unemployment is a major problem in South Africa, the unemployment rate sits at 25% which is significantly higher than that of our peers, whose unemployment rates range from 7% to

13%. Furthermore, while South Africa's peers have shown improvements in the unemployment rate in recent years, South Africa has not.

The BCG (Ikdal et al., 2015) have identified several key factors that shape South Africa's unemployment landscape that combine to make South Africa an expansive and therefore often prohibitive place to do business, making it less attractive to investors from the kind of labour intensive industries that the country needs to combat unemployment and grow the economy. Ann Bernstein, an independent development expert, stated that "South Africa needs to focus on growing low skill, labour intensive jobs. This will take a fundamental rethinking of the government's approach. Reforms to labour market regulation, competition policy and other areas are needed." The factors identified by the BCG (Ikdal et al., 2015) are:

- Education

As stated previously there is a direct link between education and the ability for individuals to find employment. There is a major problem in the job market stemming not from a lack of potential workers with the necessary education and skillset. This leaves the unique problem where there are adequate jobs available, and there are many individuals seeking employment, but the two are not compatible. Companies consistently complain that main factor impeding growth is finding workers with the necessary skills. To emphasise the benefits of education, the unemployment rate for individuals with a university degree is between 2% and 5% (Ikdal et al., 2015).

- Constraints on small businesses

Small, medium and micro enterprises (SMMEs) provide more than half of all jobs, their potential for growth and job creation is restricted. Owners and executives of SMMEs frequently cite poor access to credit, bureaucratic red tape and policies discouraging entrepreneurship as the main factors holding back growth (Ikdal et al., 2015).

- Rigidity of the labour market

Per the World Economic Forum, South Africa ranks 113th out of 144 countries (down from 76th in 2006) in terms of labour market efficiency (market flexibility and efficient use of talent). South Africa also sits last among its peers when looking at relations between labour and employers. Frequent labour unrest and lack of work ethic resulting in poor productivity exacerbate employers' limited flexibility with respect to wages, hiring and firing workers caused by rigid labour laws (Ikdal et al., 2015).

- Government is the country's largest employer

> It is not a strong economic position to have many people employed in community and social services, as well as other government jobs. However, in South Africa the government has been the largest employer since 2012, with an annual growth rate of 7% since 2000, while employment across all other sectors has only grown 3% annually. Scenarios presented in the National Development Plan 2030 suggest continued high public-services employment through expanded public-works programmes (Ikdal et al., 2015).
>
> Iraj Abedian, CEO of the equity firm Pan-African Investment & Research Services, states the following – "The public sector is being used as a source of empowerment by employing a limited number of previously disadvantaged South Africans, while actually it should be used as a source of empowerment by delivering excellent basic services as well as good quality education and health care to all South Africans" (Ikdal et al., 2015).

The National Development Plan 2030 (NDP) is integral to combatting unemployment, as stated in BCG (2015) it sets high ambitions for improving the situation. Following the NDP, the aim is to reduce the unemployment rate to 14% by 2020 and 6% by 2030, and to increase workforce participation from 53% in 2010 to 65% by 2030. To achieve these goals the current base of 15 million jobs needs to be increased by around 9 million by 2030. Through the NDP the government is focusing on the right areas, prioritising four key areas which synergise with the factors identified by the BCG (Ikdal et al., 2015):

- Transforming the economy and creating an environment in which SMMEs can thrive
- Addressing the regulatory environment and skills gap, stimulating growth of SMMEs
- Reforming the labour market
- Providing post school skill development for workers

These priorities are heavily interlinked, reforming the labour market and providing post school training for workers will contribute to stimulating the growth of SMMEs and in turn, go hand in hand with transforming the economy and creating an environment for those same SMMEs to thrive. These priorities can therefore be addressed by focusing on the labour market and skills development.

The BCG (Ikdal et al., 2015) identifies reforming the labour market as a particularly important priority. Of the various initiatives set out in the NDP on this regard, two are focused on – revisiting the dismissal process and proper enforcement of probation periods. The dismissal process in its current form ties employer's hands, it needs to be improved upon with the goal of making employee dismissals much simpler, thus reducing a big impediment to hiring. Probation periods allow employers to evaluate new hires for up to six months not burdened by unfair dismissal protections, properly enforcing these would further encourage employers to hire more.

The other key priority identified by the BCG (Ikdal et al., 2015) addressing the skill gap with post school skill development for workers. The government has set up dedicated Skills Education and Training Authorities (SETA). SETA consists of 21 agencies across different economic sectors – including agriculture, banking, and information and communications technology (ICT) –, each with the objective of developing skills needed to fill jobs their respective sectors. BCG (Ikdal et al., 2015) identifies that to date these agencies have not had much success, with poor corporate governance and lack of strategic focus, inhibiting demand-led skill development. Compounding the problem is the fact that as stated in section 3.2.1, there is a need for a shift in mind-set. A statement from Moeletsi Mbeki (ikdal et al,. 2015), outlines the issue – "South Africans have a very poor attitude to artisan and skill-based work, as a result of the stigma attached to it through the Bantu Education system during the apartheid regime." The BCG (Ikdal et al., 2015) believes that SETA needs to provide greater incentives for employers and employees to engage with the labour market. Focus is needed in promoting training for high-demand skills and large companies need incentives to take on interns and apprentices. The NDP allows provision for strengthening the workforce and shoring up the skills gap by relaxing immigration requirements in fields (including healthcare, education and financial services) where home-grown skills are scarce. This would be beneficial for businesses by improving their access to workers with the necessary skills and encouraging growth.

The BCG (Ikdal et al., 2015) believes that South Africa is on the right track in combatting unemployment with the initiatives outlined in the NDP, but stresses that efforts need to be intensified and execution is key. The kinds of efforts outlined in the NDP have shown success in other countries, examples identified by BCG (Ikdal et al., 2015) include:

- Brazil creating 5 million jobs between 2011 and 2013
- Chile creating 817,000 jobs between 2010 and 2014
- Turkey creating 4.3 million jobs between 2008 and 2013

Saudi Arabia is also on the road to tackling its major youth-unemployment problem by adopting measures including: incentivising employment of young workers, supporting on-the job and vocational training, coaching current employees to train new staff, improving workplace standards, and providing career counselling and guidance.

3.2.4 Income inequality

South Africa has severe income equality problem, ranking 148th out of 149 countries, per the World Bank's income-equality scale. BCG (Ikdal et al., 2015) reports that there have been large improvements in the standard of living of South Africans, the percentage of people living in the three poorest groups designated by the living standard measure (LSM) has dropped from 42% to 11% between 1994 and 2013. The black middle class has grown from 1.7 million in 2004 to 4.2 million in 2012. Despite this, most South Africans, still live in the marginalised class with an annual income of less than R7,248 ($617). A typical consumer living in this class has an income of around R619 per month and expenses (including food, rent, utilities and transportation) amounting to around R1102 per month, leaving them with a shortfall of R483. For many the solution is plunging themselves into the debt, while many more have no solution and simply must make do without (Ikdal et al., 2015).

Per the BCG (Ikdal et al., 2015), the number of people requiring social grants through the government's welfare system has increased from 2.7 million in 1994 to 17 million, around 30% of the population, in 2014. Social grants paid out as part of the welfare system cost the government approximately one third collected income tax, amounting to around R120 billion – three quarters of which comes from just 80,000 of the wealthiest people in the country. This sort of situation, is deeply flawed and generally avoided by healthy economies. Azar Jammine, from Econometrix, highlights that – "Without the current level of welfare and support to the poorest, people would have starved to death. We have and will in the near future need welfare in this country to avoid people falling into extreme poverty." BCG (Ikdal et al., 2015) reinforces this point by stating that should welfare be substantially reduced, or cut off entirely, 3.3 million households or more would fall into poverty.

The current welfare situation in South Africa has potential to turn into a much bigger problem in the future. BCG (Ikdal et al., 2015) identifies the risk that recipients of welfare could become dependent on the system long term and struggle to shake it off. A key goal is therefore to reduce the role that welfare plays in people's lives on in the economy. This can be done by strengthening the economy through prioritising the areas identified by BCG (Ikdal et al., 2015) and presented in the previous sub sections. Another step recommended by the BCG (Ikdal et al., 2015) is making the welfare system more efficient and orientate it to support long-term goals. Payments can be made conditional and tied to broader socio-economic goals of the country, incentives should be offered to recipients in terms of education, skill building and healthcare. This method has worked well in other countries, examples cited by BCG (Ikdal et al., 2015) include Honduras – where payments were made conditional on school attendance and health check-ups, resulting in a 2% increase in school enrolment and a 2%-3% decrease in dropout rates; in Ecuador, the percentage of the population living in poverty has decreased from 37% to 26% between 2007 and 2013 on the back of a voucher program intended to improve education and health outcomes.

The view of the BCG (Ikdal et al., 2015) is that the welfare system needs to be used not as a means of combating poverty but a tool to build up society and allow recipients to grow out of their reliance on it. Iraj Abedian, equity firm CEO, states that – "We need to ensure that welfare is channelled into building capacity in the next generation of people so that they can contribute to the economy in the future and thereby become independent of the welfare system."

3.3 Government performance indicators

In 2013 the Department for Performance Monitoring and Evaluation (DPME) published the sixth edition of Development Indicators, through these indicators government seeks to track progress made in policy implementation using quantitative measures. The latest document included 102 individual indicators across the following focus areas (DPME, 2013):

- Economic growth and transformation
- Employment
- Poverty and inequality
- Household and community assets
- Health
- Education
- Social cohesion
- Safety and security
- International relations
- Good governance

While each of these areas have a unique impact on all parts of society in South Africa, only certain indicators are relevant to the scope of this study. The focus areas of economic growth, employment, poverty and inequality, health and education are most relevant to the establishment of a titanium machining industry.

When considering the NPC (2011) diagnostics report, focus was placed on challenges involving unemployment, the quality of education, the location and adequacy of infrastructure, spatial challenges, South Africa's economic growth and the healthcare system. The BCG (Ikdal et al., 2015) report offers a convenient follow up on how some of these challenges have progressed and therefore how much of an impact the NDP 2030 is having on South Africa. The following indicators will be important to consider when gauging the success of implementing a titanium machining industry in the country.

- GDP growth
- Real per capita GDP growth
- Foreign direct investment (FDI)

- Expenditure on R&D
- Information and communications technology
- SA's competitiveness outlook
- Knowledge-based economy index
- Unemployment
- Per capita income
- Living standards measure
- Inequality measures

3.4 The cost of living in South Africa

Recently Social Development Minister, Bathabile Dlamini, in reply to a question in the National Assembly, stated that only R753 rand was enough to support a typical South African household (such a household typical consists of 1 breadwinner for 4 dependents); this included buying all required food and having money left over for non-food items. Liesl Peyper (2016) reported on a simple investigation done by fin24, which determined that it would cost a minimum of R1 146.57 to buy only basic groceries, that's R393.57 more than what Minister Dlamini claimed was enough, without considering the cost of non-food essential items.

The Pietermaritzburg agency for community social action (PACSA) releases a food price barometer monthly analysing the price of food and essentials. One part of the barometer involves comparing typical households (as described previously) across various socio-economic levels and gauging their ability to buy food and essentials based on their income, this process was adapted to include the social grant Minister Dlamini claimed was enough for food and essentials. Households are defined as follows (PACSA, 2016), and the results are shown in Figure 29.

- Household A: Dependent on social grant for five-person household as determined by social development minister.
- Household B: Dependent on old age pension.
- Household C: Average minimum wage set by Employment Conditions Commission across sectoral determinations
- Household D: Maximum income level for 60% of Pietermaritzburg households.
- Household E: Minimum wage called for by Cosatu.
- Household F: PACSA's idea of minimum wage accessing a basic life of dignity.

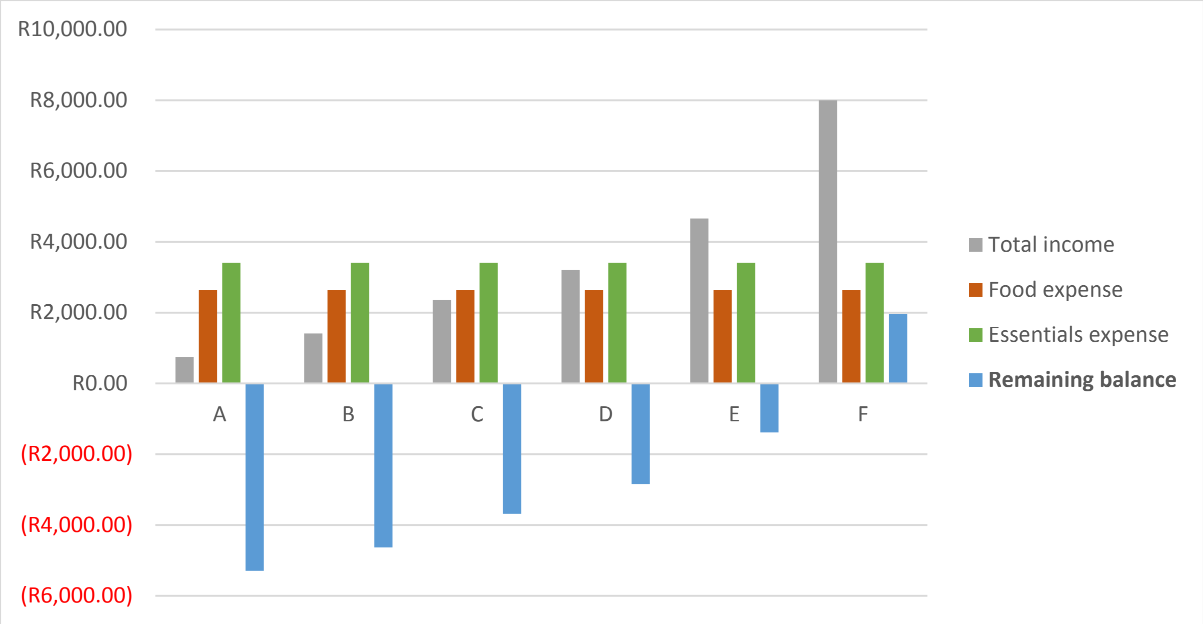


Figure 29: Comparison of households at different socio-economic levels (adapted from PACSA, 2016)

PACSA calculates the monthly cost of food at over R2500 (value varies depending on month) and essential expenses over R3000. It is clear without any further analysis that Minister Dlamini's proposed social grant is grossly insufficient to support a household of five members. What is clear from the graph that even the minimum wage called for by Cosatu doesn't cover all food and essentials expense. Only PACSA's proposed minimum wage of R8000 is enough to cover basic expenses and have money left over for savings and emergencies. However, such a minimum wage is not sustainable in many sectors.

3.5 Summarising the socio-economic aspects

In this section, we looked at how the NDP 2030 was developed, a BGE report on problems facing South Africa, what performance indicators government uses to gauge how South Africa is doing and briefly at the cost of living in South Africa

Key points to take away include:

- South Africa faces many challenges which the government plans to address with the development of NDP 2030.
- Key problems highlighted by the BCG, which are in line with some of the challenges identified by the NPC
- Unemployment, poor education and poor healthcare are problems that need to be addressed to break the poverty cycle.
- As per the NPC (2011), South Africa is a net exporter of minerals, the economy is supported by commodity prices which is not sustainable in the long term and

undermines the ability to develop downstream manufacturing industries and increase the country's share of value-ad.

- Relevant government performance indicators against which any future titanium machining industry should be measured
- The cost of living for a typical South African household

The above points provide on where a titanium machining industry needs to have an impact to be worthy of Government investment. Such an industry needs to address the poverty cycle, influence the countries reliance of export of raw material and increase the standard of living of South Africans that fall within its influence.

4. Techno-Economic aspects

This chapter focuses on the techno-economic aspects at play. The Industrial Policy Action Plan for South Africa is explored and South Africa's manufacturing competitiveness is looked at. This chapter also looks briefly at the roll of the TiCoC. Finally, this chapter covers the definition of a machining process chain for titanium and the development of an "ideal" machining cell model.

4.1 The Industrial Policy Action Plan

Every year the Department of Trade and Industry (dti) publishes the Industrial Policy Action Plan (IPAP); an annual action plan to strengthen industrial policy instruments, building on what previous iterations have achieved, and halting programmes found ineffective in practice (dti, 2015). As industry is one of the biggest and most significant sectors in the South African economy, IPAP plays a key role in the future development of the country; in the context of this this study IPAP has added significance in that it has a direct impact on titanium machining and the broader titanium industry.

Along with IPAP the dti released a companion piece to summarise and highlight key points. One of the issues discussed was the importance of industrial policy; per the dti (2015) the following is true for the industrial sector:

- Backbone of the economy

  The industrial sector has the highest economic and employment multipliers, and the strongest linkages to all other sectors.

- Fosters important growth and productivity factors

  A strong industrial base is necessary for increased economic growth and technical progress. Manufacturing is key to the development and competitiveness of value added exports and is 15% higher than the overall average productivity of all sectors. It is responsible for productivity growth in other sectors and a critical driver for research, development and innovation.

- Operates as a hub to the wider economy, offering an important market for supplies and services from other sectors

  Upstream and downstream demands on value chains greatly benefit business services and other sectors. In South Africa, the linkages between manufacturing, mining and agriculture are critical to help consolidate sustainable services (dti, 2015).

- Generates strong positive spill overs

Due to its capacity to generate positive and significant spill over effects on the rest of the economy; manufacturing remains relevant and decisive within the South African economy, despite being placed under extreme pressure during tough economic times, such as the financial crisis of 2008/9. Manufacturing creates demand, has high output and employment multipliers and demands quality work. It creates demand for a large range of upstream inputs and services, while stimulating significant downstream economic activity in services, maintenance and retail. Every additional R1 unit of investment spending in the manufacturing sector generates 1.13 units of additional output to the total economy; in contrast construction generates 0.81, mining 0.6, finance 0.49, transport and communication 0.03, and electricity 0.03. Every R1 million of additional investment spending in the manufacturing sector will create about 3 decent and sustainable jobs; compared to 2.5 jobs in construction, 1 in finance, 0.5 in mining, 0.1 in transport and communication, and 0.1 in electricity. The jobs created in manufacturing are also on a higher level, and of a higher quality than many other sectors, offering higher wages and better career prospects. Modern industry is building its core workforce around employees who have completed only secondary education rather than tertiary – a trend that is significant in South Africa as many job seekers do not have the opportunity to complete tertiary education –, however wages remain above average in every skill class (dti, 2015).

- Depends on and spurs higher quality education

The growth of the industrial sector is inexplicably linked to the improvement of quality education; the sector both needs a workforce with core skills of a certain standard while also creating opportunities for further education and training of its workforce to build and maintain a competitive advantage. Sustainable industrial jobs and wages contribute strongly to aggregate demand in the economy and are dependent on a workforce that has strong STEM skills (science, technology, engineering and mathematics) that are constantly being revised and improved through both in-house as well as public sector secondary and tertiary schools (dti, 2015).

IPAP is heavily linked to the NDP 2030; where the NDP sets the overall tone and vision for South Africa, IPAP provides a framework and targeted actions geared towards sustained and deepening industrialisation (dti, 2015). Linking IPAP to the overall vision for South Africa heading towards 2030, the following sections of the NDP are highlighted in IPAP (dti, 2015), highlighting the need for the country to move away from its resource intensive growth path and addressing unemployment, as discussed in the previous section:

- SA needs to develop a more competitive and diversified economy, with a higher global share of dynamic products and greater depth and breadth of domestic linkages

- Resources can be both a blessing and a curse, what they turn out to be is critically dependent on the coherence of investment and regulatory policy
- SA needs to move steadily away from an exchange rate linked primarily to commodity prices and towards one based on the sophistication of country's overall export basket
- There is a need for deepening the productive base in mining, agriculture, manufacturing and services, intensified simulation of local and foreign markets and strengthening of conditions to support labour absorbing activities.

IPAP is also inexplicably linked to the MTSF as one of the key pillars of radical economic transformation in South Africa, predicated on the rapid and inclusive growth in the productive sectors of the economy and the creation of a skilled and capable workforce to support an inclusive growth path (dti, 2015).

IPAP can be separated into transversal and sector-specific (sectoral) focus areas, highlighting that it is a collaborative product of the Economic Cluster of government hinging on cooperation and support between all government departments, state owned companies and developmental finance institutions. Exploring the IPAP document in full is beyond the scope of this study. Figures 30, 31 and 32 summarise the different focus areas of IPAP. Key transversal focus areas include innovation and technology, and industrial financing. In the first sectoral focus cluster, none of the focus areas directly relate to a titanium industry however the automotive industry provides a potential market for limited titanium products and the fabrication, capital and rail transport equipment focus area provides a potential framework within which a titanium industry can grow. In the second sectoral focus cluster oil and gas, aerospace and defence, and ship/boat building focus areas provide further potential markets for titanium products. The focus area of leveraging SA's mineral endowment is a corner stone of the conclusions this thesis is trying to draw – South Africa has great wealth of titanium resources and real potential for developing downstream manufacturing to reap the benefits of the titanium value chain (dti, 2015).

The innovation and technology focus area is particularly important, as recognised by the dti (2015) in IPAP; science, technology and innovation (STI) are key drivers for long-term economic growth. In the modern day, the production and dissemination of knowledge is key to gaining a competitive advantage, creating wealth, improving the quality of life and therefore significant to economic growth. Development and growth in STI are a key focus for the NDP and the overarching framework within which this project falls. Key programmes of the innovation and technology focus area are (dti, 2015):

- Improving linkages between knowledge production, utilisation and innovation, and industrial growth

- Large R&D programmes in knowledge-intensive areas
- Technology commercialisation strategy
- Harmonisation of innovation support programmes

This thesis along with all research done under the TiCoC, with focus on CSIR led research into titanium powder, fall within the scope of these programmes.

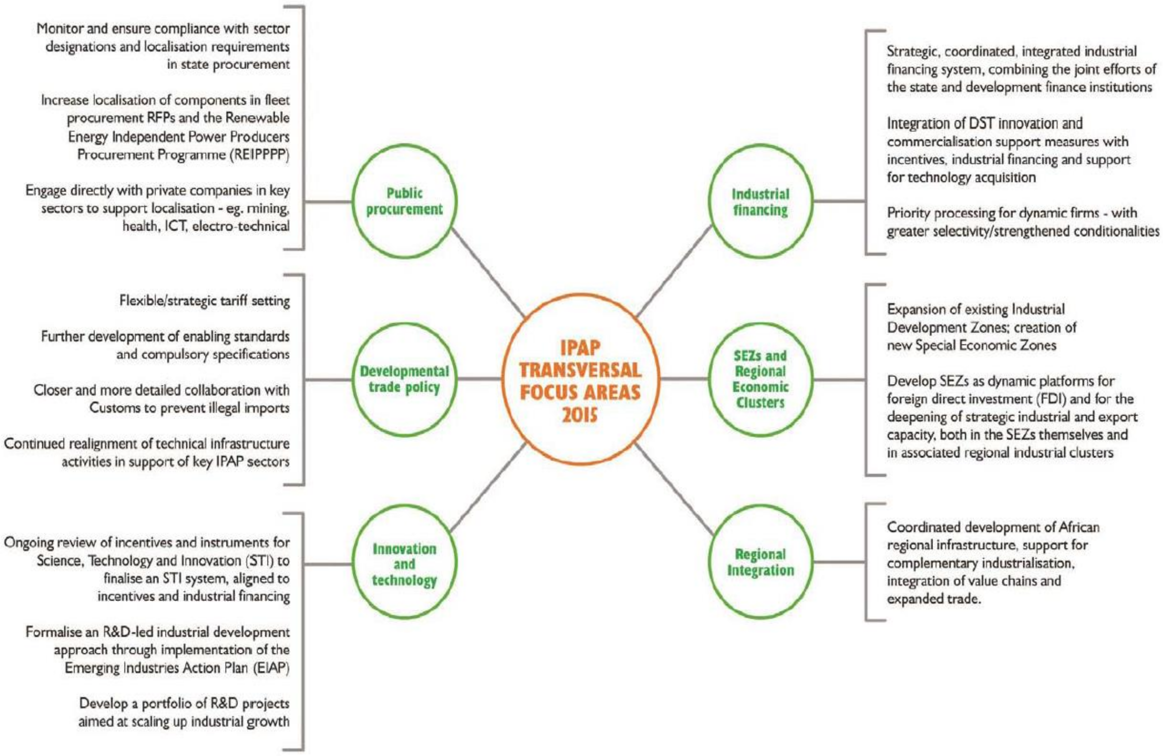


Figure 30: IPAP transversal focus areas (dti, 2015)

The metal fabrication, capital and rail transport equipment focus area does not strictly deal with titanium in its programmes, however this can be attributed to the specialised nature of titanium products and lack of an established titanium manufacturing industry. The programmes do however provide framework within which any future industry can grow; the industries covered under this cluster form an important component of any industrialisation path and are key drivers of the manufacturing sectors overall competitiveness, producing products, applications and services that are used throughout the economy. Per the dti (2015), key programmes of the metal fabrication, capital & rail transport equipment focus area are:

- Continued competitiveness enhancement programmes deployed at company level, together with dedicated training
- Addressing costs and access to key intermediate inputs

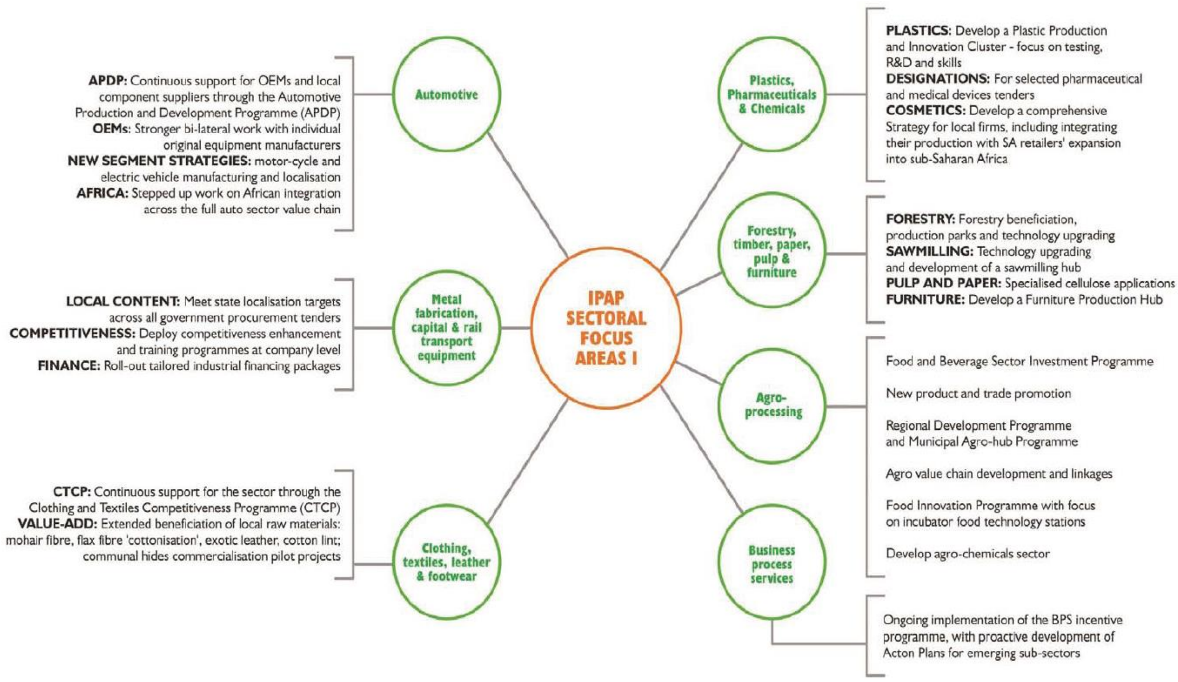


Figure 31: IPAP sectoral focus areas, cluster 1 (dti, 2015)

The focus area of leveraging South Africa's mineral endowment or more aptly defined as the focus on primary minerals beneficiation and construction is key to the development of a titanium industry in South Africa. Per IPAP, a 2010 study estimated South Africa's non-energy mineral resources to have a value of 2.5 trillion USD, while a separate study estimated in 2012 estimated their value at over 6 trillion USD. However, the biggest problem remains the predominance of exporting raw materials, with the dti claiming that over the past five years 50% of total mineral exports were in an un-beneficiated form. As has been alluded to in previous chapters, the immediate and mid-term future of the sector will be largely dependent of the degree of success that can be achieved in rapid development of industry to extract value from the entire minerals value chain. Among the opportunities presented by this focus area – employment creation, transfer of technology and skills development, and creation of economic linkages through supplier development are significant to development of a titanium industry. Key programmes in this focus area include (dti, 2015):

- Development of mineral beneficiation action plans (MBAP)
- Stimulation and expansion of the capital goods sector
- Viability of unlocking iron ore and titanium resources in the Bushveld Complex
- Leveraging the infrastructure-build programme to increase local content of construction materials

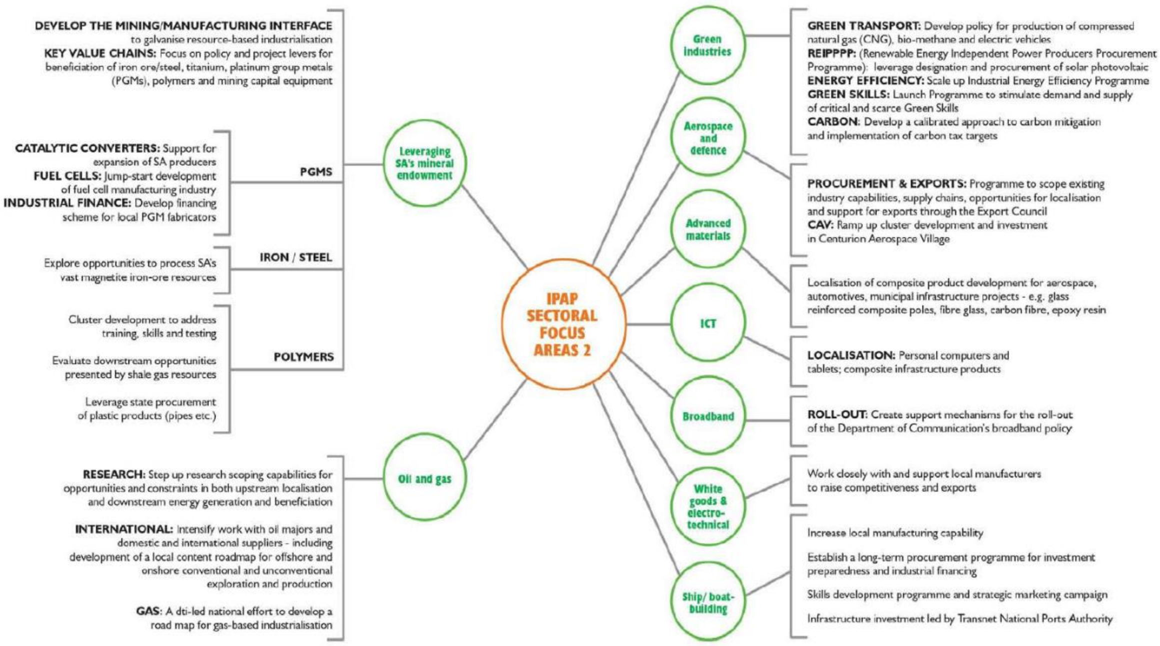


Figure 32: IPAP sectoral focus areas, cluster 2 (dti, 2015)

During his budget speech in Parliament in 2015, Trade and Industry Minister Rob Davies, committed to five pillars aimed at boosting industrial development in South Africa, as reported on by Matthew le Cordeur (2015) These five pillars are an apt summation of the critical programmes identified in IPAP 2015 to achieve a higher-impact industrial policy; they not only reinforce IPAPs aim of building upon previous iterations and position it to address some of the challenges identified in Section 3.1 in the key areas of unemployment, infrastructure, the resource intensive economy and inclusive development; but also fit with the scope of this thesis as they identify key areas where titanium machining and the titanium industry can have a significant impact on the future of South Africa. The five pillars, including quotes from Minister Davies' speech, are (le Cordeur, 2015):

1. Infrastructure-driven industrialisation

   "Ensure that the very substantial build programme supports local industrial development" (le Cordeur, 2015).

2. Resource-driven industrialisation

   "Aimed at leveraging the mineral resources endowment to support higher levels of downstream beneficiation and value addition, whilst systematically building up both the demand and competitive advantages South Africa enjoys in the upstream mining, transport and capital goods sectors" (le Cordeur, 2015).

3. Advanced manufacturing-driven industrialisation

"The dti will continue to build an integrated system of industrial financing, incentives and export support with a special focus on lead and dynamic companies that can compete effectively in export markets," said Davies. "It encompasses a strong commitment to support emerging black industrial entrepreneurs." (le Cordeur, 2015).

4. Procurement

"This focuses on strengthening the localisation of public procurement, building on the lessons learnt through the implementation of various policy instruments over the past few years." (le Cordeur, 2015).

5. Regional economic integration

"This centres on maximising the opportunities presented to the domestic economy by a growing market on the African continent, driven by high growth in the region, strong consumer demand, infrastructure development and resource exploitation" (le Cordeur, 2015).

4.2 Manufacturing competitiveness

4.2.1 Global manufacturing competitive index

Deloitte Touche Tohmatsu Limited (DTTL) in partnership with the US Council on Competitiveness have undertaken multi-year global competitiveness in manufacturing initiative based in part on the responses of more than 550 CEOs and senior manufacturing executives. The index, published triennially, ranks countries competitiveness based on several factors as shown in Table 10 and Figure 33 below. Table 11 gives the 10 factors that were used to rank competitiveness in 2010 and 2013, however these factors were reworked and new factors were added for 2016 as shown in Figure 33. The previous factors are still relevant and will be looked at in the following section in a South African context. The factors themselves are ranked by their perceived importance to competitiveness.

Table 10: Factors driving competitiveness (DTTL, 2013)

Rank	Competitiveness driver
1	Talent-driven innovation
2	Economic, trade, financial and tax system
3	Cost and availability of labour and materials
4	Supplier network
5	Legal and regulatory system
6	Physical infrastructure
7	Energy cost and policies
8	Local market attractiveness
9	Healthcare system
10	Government investments in manufacturing

South Africa's position has slipped since 2010 despite initial predications of a rise in competitiveness:

- In 2010: South Africa was ranked 22nd out of 26 nations and was predicted to climb to 19th in the next five years
- In 2013: South Africa had fallen to 24th out of 38 nations and was expected to fall further to 25th in the next five years
- In 2016: South Africa has fallen to 27th out of 40 nations however it is expected to rise to25th in the next five years

South Africa's decline in competitiveness is shared by fellow emerging economies and BRICS (Brazil, Russia, India, China, South Africa) partners; it was expected in 2010 that three of the original BRIC (Brazil, Russia, India, China) countries would dominate the top of the competitiveness index and despite drops by both Brazil and India the expectation was repeated in 2013. This domination by emerging economies never occurred despite China's continued domination of the top spot; by 2016 Brazil had joined Russia in a steep decline in competitiveness ranking, plummeting from fifth in 2010 to 29th in 2016 while India also declined steadily. Figure 34 shows the BRICS nation's competitiveness ranking over the time, the dashed line represents the expected change in index (over the next five years). It is interesting to note that despite constant decline by most of the BRICS nations there is continued optimism for a turnaround.

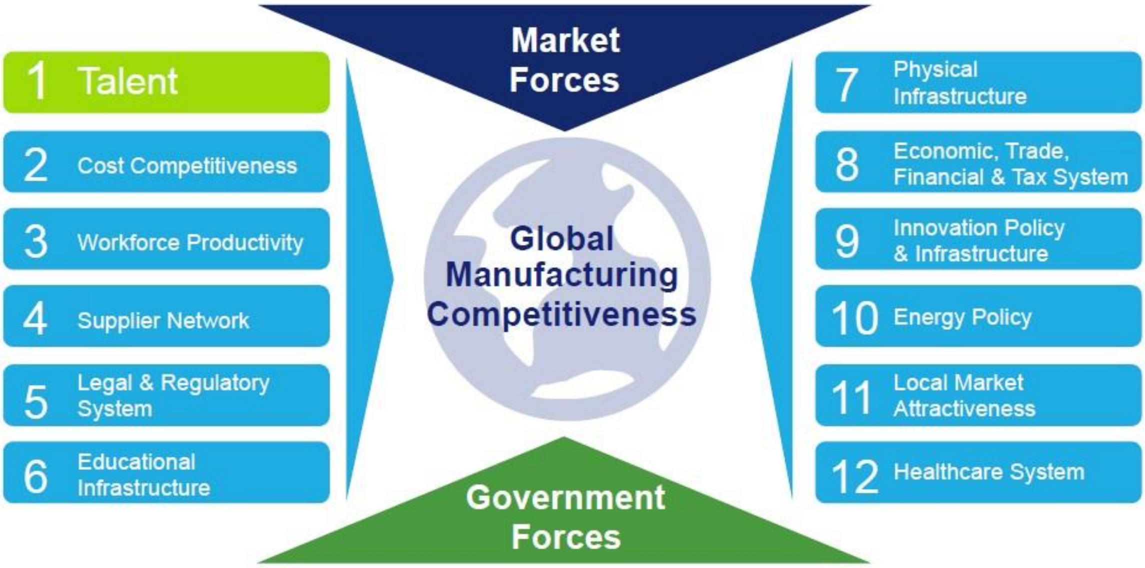


Figure 33: Drivers of global manufacturing competitiveness (DTTL, 2016)

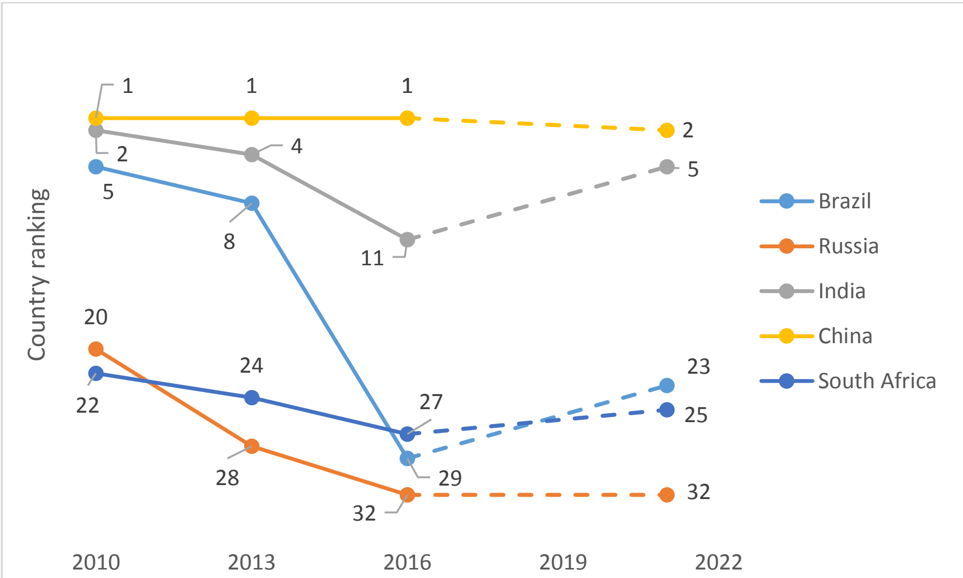


Figure 34: Competitiveness ranking of BRICS nations 2010-2016 (DTTL, 2010 & DTTL, 2016)

4.2.2 Enhancing South Africa's competitiveness

In response to South Africa's two place drop in 2013 and then expected continued decline, Deloitte South Africa partnered with the Manufacturing Circle to conduct a local manufacturing competitiveness survey in line with the global one, with the objective of understanding the factors at play in a South African context and developing a roadmap to allow the country to improve its position and compete globally (Deloitte, 2013). The manufacturing competitiveness drivers from Table 11 were re-ranked from a South African perspective as shown in Table 12.

Table 11: South African ranking of competitiveness factors (Deloitte, 2013)

Global Rank	SA Rank	Competitiveness driver	Respondent comments
3	1	Cost and availability of labour and materials	Sector was built on cheap labour; costs in SA have increased faster than globally; no commensurate increase in productivity
8	2	Local market attractiveness	Domestic market is small; threat of cheap imports; policy uncertainty; high input costs; limited skill base
7	3	Energy cost and policies	Cost increase envisaged by Eskom's power build programme; dependent on individual respondent's power demands
2	4	Economic, trade, financial and tax system	Government has role to play in creating environment for sector to thrive; need for improved incentives or import protection
6	5	Physical infrastructure	While proposals laudable, need to expedite process; improve rail, road and port infrastructure
4	6	Supplier network	-
1	7	Talent-driven innovation	More fundamental issues to deal with – primary and secondary education; diluted intellectual skills in country; innovation still needed
10	8	Government investments in manufacturing	Focus on long-term issues; need for greater collaboration and improved relationship between government, labour and business
5	9	Legal and regulatory system	-
9	10	Healthcare system	-

As seen in the table, in a South African context, local market attractiveness as well as energy cost and policies are considered significantly more important, and a lot less emphasis is placed on talent-driven innovation. As with the global competitiveness index, very little importance is placed on healthcare; looking back to the previous chapter, healthcare is one of the key challenges facing South Africa from a socio-economic stand point and it is this authors belief that more consideration needs to be given to it; it has a direct impact on the labour force and therefore the potential to be have a significant impact. Per Deloitte (2013), the following themes need to be focused on to shift South Africa's competitive index:

- Proactive engagement between government, labour and business

It is critical that a tryst-based working relationship exist between all stakeholders that is government, labour and industry. As stated in comments in Table 12, there is a need to focus on the long-term vision and key building blocks and actions need to be agreed between all parties. An economic indaba is a possible way of creating positive momentum (Deloitte 2013).

- Regulatory adjustments

There is a need for government to review duties for in-bound products to make them more comparable with other emerging economies. More stringent control on administered prices to keep them competitive is also required, along with increased flexibility in labour laws. The NDP 2030, as discussed in the previous chapter needs to be prioritised (Deloitte 2013).

- Education

A better standard of education is required in South Africa; increased investment is needed to achieve this. Existing longer-term solution needs to be made a priority and in the short-term focus needs to be placed on artisan training and on an overhaul of Sector Education and Training Authorities (SETAs) (Deloitte 2013).

- Incentives

Important strategies include the rapid implementation of current manufacturing initiatives, subsidies and import protection (Deloitte 2013).

- Industry collaboration

The buyback South Africa campaign needs to be supported, encouraging consumers to buy locally produced products and support the local service industry; emphasis must be placed on business and labour agreeing on prioritising jobs and on local beneficiation. A sub-Saharan body to coordinate and fund cross-border infrastructural projects is needed (Deloitte 2013).

- Labour

Important stakeholder in the future of the manufacturing sector; wages and job creation need to be engaged upon and labour needs to be depoliticised (Deloitte 2013).

4.3 Titanium Centre of Competence

The Titanium Centre of Competence (TiCoC) was established by the Department of Science and Technology, to capitalise on and add value to South Africa's strong position in the supply of titanium resources. The TiCoC, managed by the CSIR, compromises a large network of research institutions, universities and private companies all with the aim of enhancing South Africa's competitiveness in the titanium market. The structure and role players in the TiCoC are shown in Figures 35 and 36. In 2013, per Dr Willie du Preez, the South African resource pool consisted of 80 permanent researchers and 20 postgraduate students.

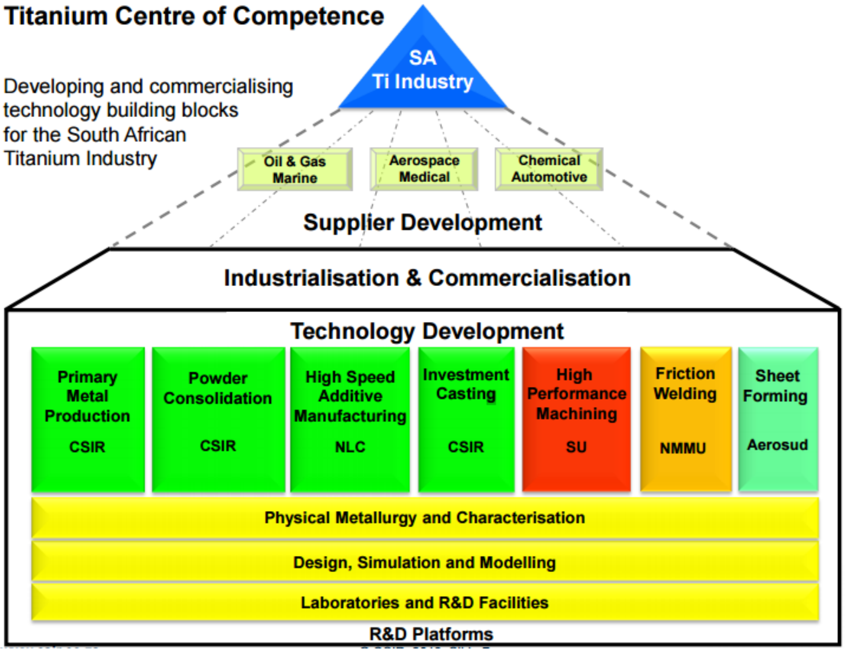


Figure 35: TiCoC Model (Du Preez, 2013)

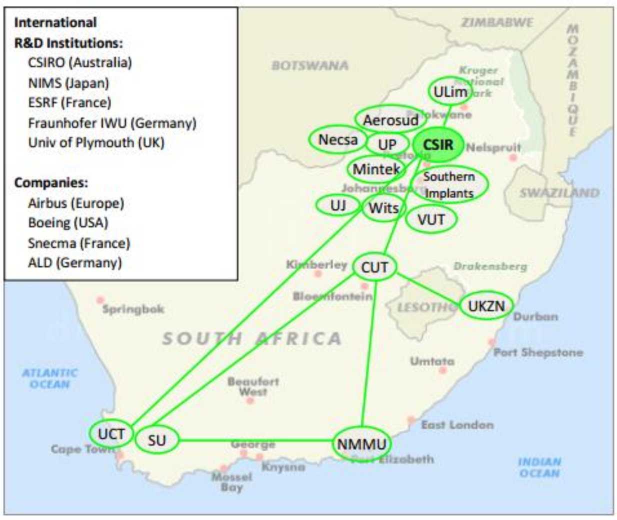


Figure 36: South African resource pool (Du Preez, 2013)

4.3.1 High Performance machining research

One of the technology development areas of the TiCoC, where this thesis is located, is the development of high performance machining capabilities. The TiCoC along with researchers at the University of Stellenbosch developed a road map for the development and commercialization of titanium machining as shown in Figure 37.

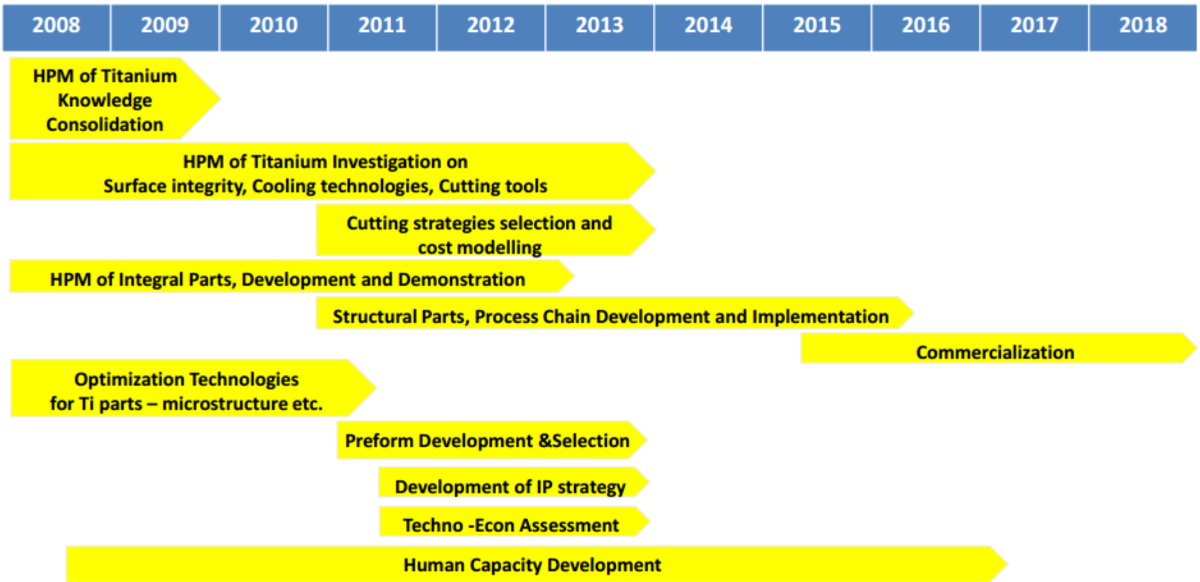


Figure 37: Roadmap for titanium machining (Du Preez, 2013)

As part of the high-performance machining project the TiCoC has made great strides in the fields of additive manufacturing, investment casting and near net shaping, as well as the establishment of a pilot plant for a titanium powder production process. As this thesis falls under the same initiative under the TiCoC as these projects, it is sufficient to mention them without going into detail.

4.3.2 Machining process chain

Titanium machining operations follow several processes to transform an idea for a part and a raw titanium mill product or billet into a finished part that matches customer specifications. This sections starts of by first looking at six basic stages in a machining operation from product design, through machining, to dispatch to customer. These stages are then expanded on both internally and externally: internally to look at all the operations and inputs of the stages in more detail; and externally putting the actual processes in a black box and looking at the external influences to describe an "ideal" machining cell model which can be used as a simplified template to describe a SMME titanium machining operation.

4.3.2.1 Basic titanium machining process chain

The machining process can be modelled a chain of six individual stages of information and material flow that help transform a conceptual idea into finished product that can be installed in its application area. The six stages are shown in Figure 38 below:

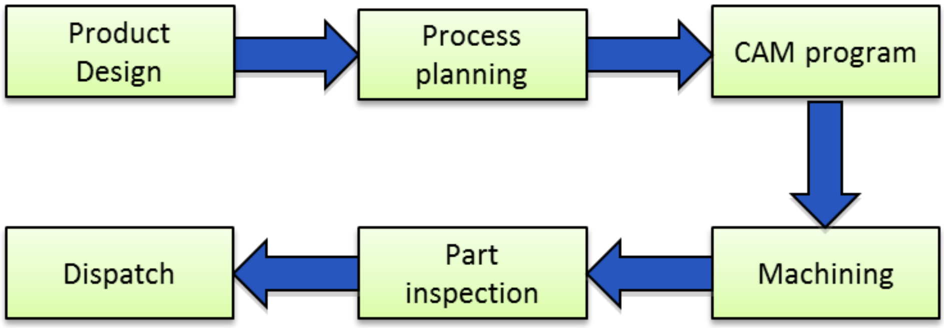


Figure 38: Simplified machining process chain

The individual stages each play a unique role in transforming the product and adding value; these stages can be detailed and expanded to create a comprehensive machining process chain. In the context of this study it is specified as a titanium machining process chain and compromises all the processes that take place in the final stage of the titanium value chain as described in previously; the output of which is a finished titanium product. The full titanium process chain, highlighting added procedures and data packs is presented as Figure 38.

- Product design

Product design does not necessarily entail designing a new product from start to finish. In the context of this study, product design refers to taking the design from the customer and converting it into a usable form, be it drawing a CAD model from a drawing or porting into from one CAD software package to another.

- Process planning

Process planning entails planning all the details about the machining process that will follow: is this a prototype or production part, batch size, one of run or recurring, is the part prismatic or rotational, what type of billet will be used (mill product or preform), which machining centre will be used, what tools and fixtures will be used, how often and when will inspections take place, etc.

- CAM programming

CAM programming entails programing how the product will be machined by the machining centre, the tool math that will be followed, what tools will be used, etc.

- Machining operations

Machining is the operation of removing material from the billet, turning it into the final part.

- Part inspection

Both dimensional and mechanical property inspection is done on the part to ensure it meets customer specifications. The amount and type of part inspection that is done is governed by the process plan.

- Dispatch

The finished parts/batches are packed and shipped to the customer.

4.3.2.2 Expanding the titanium machining process chain

As part of the research into titanium machining conducted for this thesis, the basic titanium machining process chain was expanded jointly with Professor Dimitri Dimitrov, Mr Konrad von Leipzig and Mr Bruce Beecroft. The resulting expansion is shown in Figure 39. This expansion details all steps in the transforming an idea for a component into a finished product, and highlights all external inputs into the system.

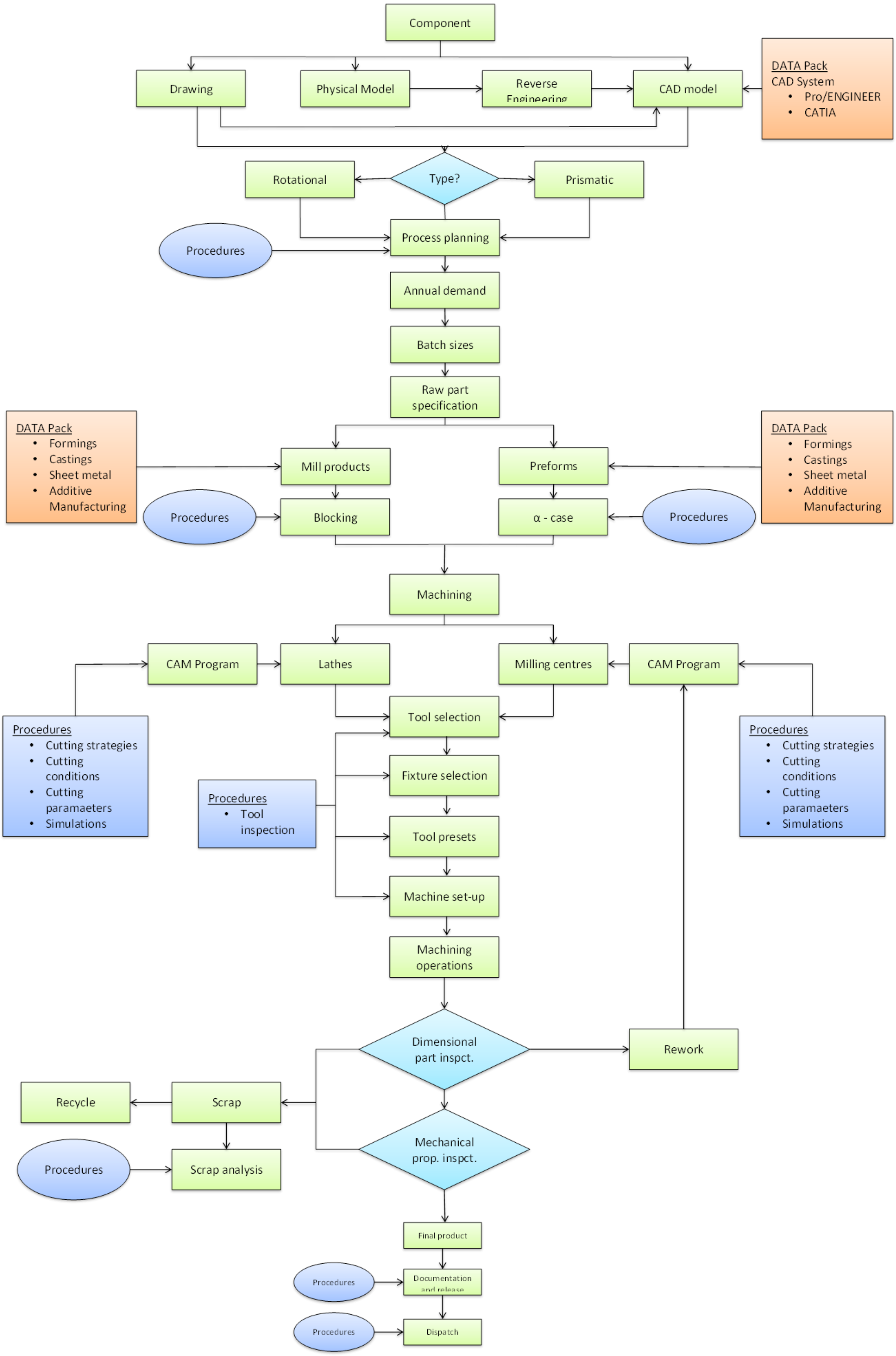


Figure 39: Titanium machining process chain

4.3.2.3 Digital manufacturing

One of the biggest advances in machining operations was the introduction of digital manufacturing; as important as the process chain itself is the method or philosophy with which it is implemented. Digital manufacturing as defined by Siemens is the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) visualisation, analytics and various collaboration tools to create product and manufacturing process definitions simultaneously. In terms of the titanium machining process chain described previously, this involves integrating all steps in the production process into a computer based system, minimising part handling and paperwork. The main advancement in the machining process is the elimination of breaks in the digital flow of information from CAD model to machining centre; to illustrate the digital manufacturing concept for titanium machining a section of the process chain shown in Figure 39 has been adapted and shown in Figure 40, to highlight the uninterrupted flow of information. It is important to note that despite visual differences between the section of process chain shown below and the full titanium machining process chain shown previously they are one and same, Figure 40 is merely adapted to highlight the flow of information and monitoring of the process to gain knowledge and experience for the future.

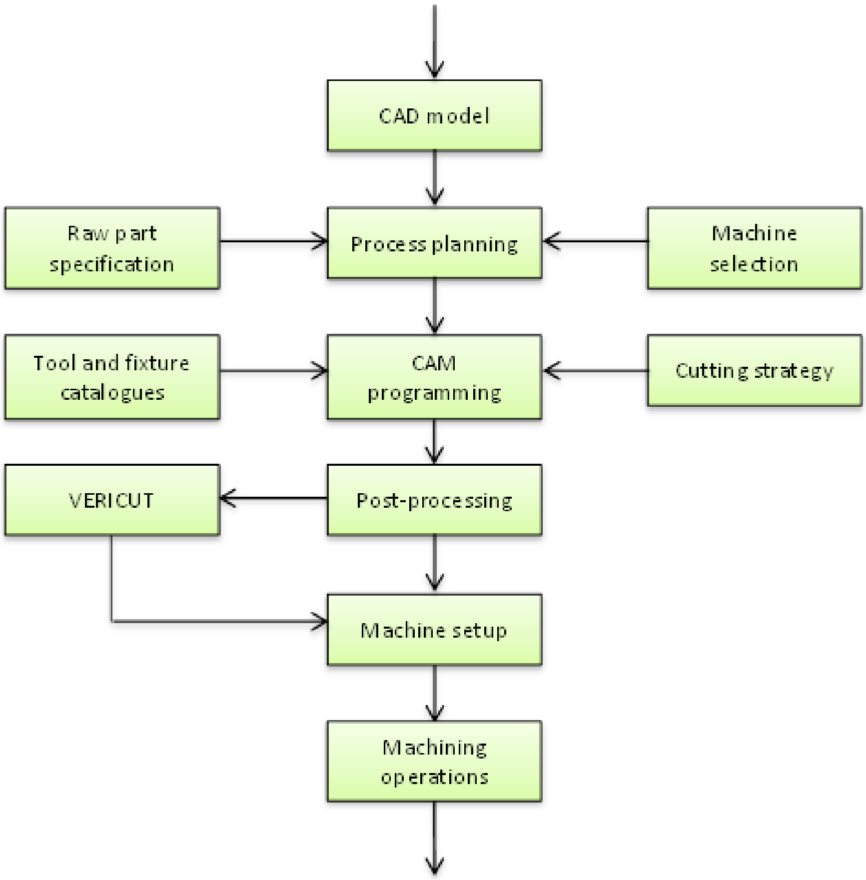


Figure 40: Digital manufacturing information flow

Seamless digital information transfer takes place all the way from the CAD model to machine setup and machining operations. Machine selection, raw material specification, tool and fixture catalogues, and cutting strategy are all key inputs into the programming process. As a control measure the entire machining process is first simulated using verification software such as VERICUT. This allows a level of confidence in the machining process that eliminates the need for intermittent part inspection, meaning that once the billet is placed in the machining centre it is not removed until taken out as a finished product. One of the biggest advantages of digital manufacturing is the ability to build on history and use experience and knowledge in planning and setting up new production, allowing the process to be optimised before it has even begun.

Digital manufacturing thus has several perceived advantages over traditional methods:

- Reduction in overall process time
- Less part handling
- Reduced risk of need for rework/scrap
- Fewer inspections
- Lower overall costs

As titanium machining, will inherently involve higher costs due to the difficulty associated with machining it, it is critical to ensure that parts are cut right the first time, thus use of digital manufacturing is critical

4.4 "Ideal" machining cell

The concept model for the "ideal" machining cell is shown in Figure 41, internally the machining cell would follow the titanium machining process chain and digital manufacturing strategy already highlighted earlier in this section.

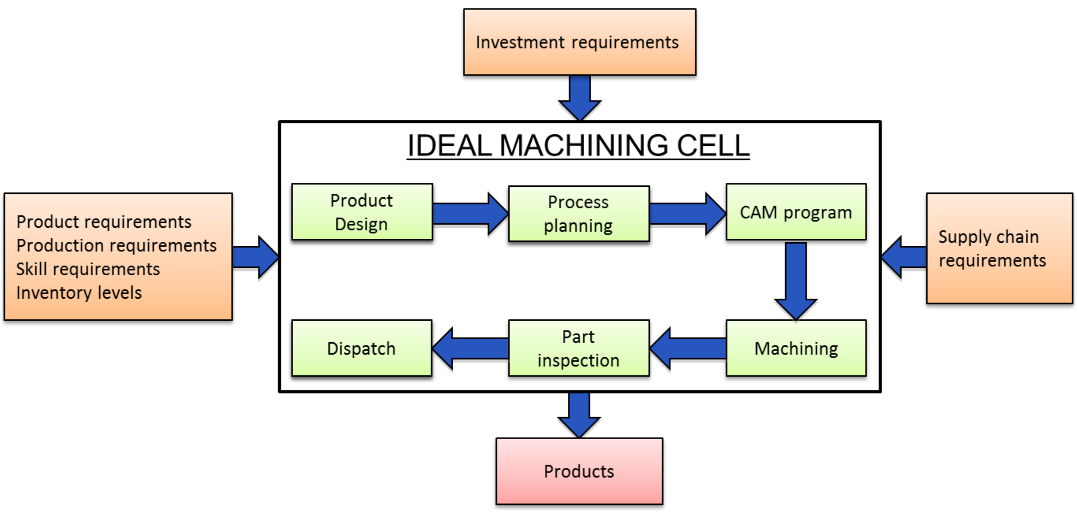


Figure 41: "Ideal" machining cell model

The machining cell model includes all the processes (functions) and components required to turn a raw billet of material into finished component and therefore occupies the last stage of the titanium value chain. Its internal processes can be simplified into the six stages of machining process operation. The key functions of the cell are:

- Product design
- Process planning
- Machine programming
- Machining
- Part inspection
- Dispatch

Each of the above listed functions is critical to produce products to the correct specifications. The functions need to be adapted to suit a titanium machining operation as there are a few differences compared to machining other metals. As titanium has a poor thermal conductivity, different considerations need to made for tool selection, cutting strategy and cooling method. If these are kept in mind, and the correct components are used, the same machining cell can be used to machine both titanium components and components made from other metals. The key components of the machining cell are:

- CAD and CAM software
- CNC machines (machining centres) – along with tools and fixtures
- Inspection equipment

Of these, the most important limiting factor with regards to ability to machine titanium is the machining centre. While most machining centres are theoretically capable of achieving the task, they will not necessarily perform efficiently. Higher tool wear, longer machining time, and products not to specification are just some of the problems that can be faced when using incorrect equipment; which leads to a non-economical process.

While the machining centre itself is critical, incorrect cutting strategy can cause even the perfect machine to produce substandard parts and wear out tools at a higher than expected rate. It is therefore important to ensure that all the above-mentioned functions and components are integrated and work together as much as possible, providing information for downstream processes but also feedback for upstream processes.

There are many inputs into the machining cell that need to be considered. These can be grouped as follows:

- Investment requirements
- Supply chain requirements
- Product requirements
- Production requirements
- Skill requirements
- Inventory levels

One of the most important inputs to consider for setting up the machining cell is its location and the associated investments required. It is important to determine the following:

- How much floor space is required?
- Will a new or existing structure be used?
- What are the local electricity and water rates?
- What are the local average labour rates?
- How many and what type of machining centres are required?
- Will inspections be carried out in-house, and what equipment is required?
- What kind of peripheral equipment is required, including computers for CAD and CAM programming and associated software?

Before the other requirements can be explored in detail it will first be necessary to decide on a preliminary road map for commercialisation and determine what sort of market is being aiming at, and what sort of output can reasonably be achieved in the next 5, 10, 15 years. For breaking into the titanium machining market, the output of established global producers needs to be determined to identify where a South African titanium machining industry can fit in. Another important decision is which marker segment to aim for. The primary markets for titanium products are in the aerospace, biomedical, chemical, automotive, marine and industrial. Industrial partners and present research under the TiCoC has focussed on machining parts for aerospace and medical sectors. In general titanium parts are:

- Small volume
- High complexity
- High added value

Consideration must be given to the industrial sector, particularly as China, a strategic trading partner and fellow BRICS member is rapidly expanding in the consumption of titanium mill products for this sector. Whichever sector is aimed for it will be a challenge to break into as you not only have to compete with established and likely better funded enterprises with lower overheads, but also need to convince the customer to move away from what is likely a longstanding supplier. Other possibilities for breaking into the market include.

- Striking a deal with a customer/supplier to share the load
- Entering the market with a new product
- Part of Government deal – where local suppliers are used to produce some components for the finished products, e.g. airplanes.

Taking the "ideal" titanium machining cell further the following questions need to be addressed to implement and test it with an industrial partner:

1. What are the start-up capital requirements?
2. What are the human capital requirements?
3. What are the infrastructure requirements?
    - Floor space
    - Number and type of machining centres
    - Overhead costs
    - Location
4. What type of products will be produced?
    - Prototyping or production products.
    - Degree of added value (High, medium, low – e.g. a simple bracket, turbine blade)
5. Will the market for the products be local or international?
6. Will the supplier of mill products be local or international?

The following performance measures were identified to gauge the performance of the machining cell:

1. Out and costs per m^2 of floor space
2. Ratio of programming to machining hours
3. Cost benefit analysis of location
4. kg of finished product per kWh

4.5 Summarising techno-economic aspects

In this chapter, we looked at the Industrial Policy Action Plan, South Africa's latest rating per Deloitte's latest manufacturing competitiveness index, the Titanium Centre of Competence, and a model for an "Ideal" machining cell.

Key points to take away include:

- As per IPAP (dti, 2015), every R1 unit of investment spending in the manufacturing sector generates 1.13 units of additional output to the total economy, this is much more beneficial for the economy than other sectors of the economy all of which provide a less than 1 to 1 ratio.
- The five pillars of industrial committed to by Trade and Industry Minister Rob Davies.
- South Africa's continued fall per Deloitte's manufacturing competitiveness index.
- Competitiveness drivers that need focus to take the country forward
- The TiCoC and its role in driving titanium beneficiation forward
- The titanium machining process chain
- The flow of information in digital manufacturing and the benefits it provides in machining
- The "ideal" machining cell developed

5. Soft systems modelling of the impact of titanium machining

In this chapter the role of titanium is examined by identifying how it fits into government plans and policies and how it can be used to help address the challenges facing South Africa with the use of a soft system modelling approach.

To demonstrate the role that titanium machining and the broader titanium industry can play in the South African economy, and how it can help address the challenges facing the country, a soft systems approach is used to describe the real-world problem situation, identify the root definitions using systems thinking and present conceptual models of key system definitions. The concept model of an "ideal" titanium machining cell, defined in the previous chapter is used as part of the soft systems approach.

5.1 Defining the problem situation

The first two stages of the soft systems methodology as described by Peter Checkland (1991) are used to describe the "problem situation" in all its richness to gain an understanding of all role players and processes at play. The area of interest is described without defining the problem. For this study the area of interest has two distinct parts, and the aim is to try and link these together. The two parts are:

- South Africa's present socio-economic situation
- The titanium industry in a South African context

As was described in previous chapters, South Africa's socio-economic situation revolves around the key challenges facing the country, as defined by the NPC (2011) in developing the NDP 2030 and refined by the BCG (Ikdal et al., 2015); of the challenges facing the country the key problem areas are – education, unemployment, healthcare, and income inequality. These four areas form part of a cycle that needs to be broken for social and economic growth to take place, this cycle is referred to as the Poverty cycle and is shown in Figure 42.

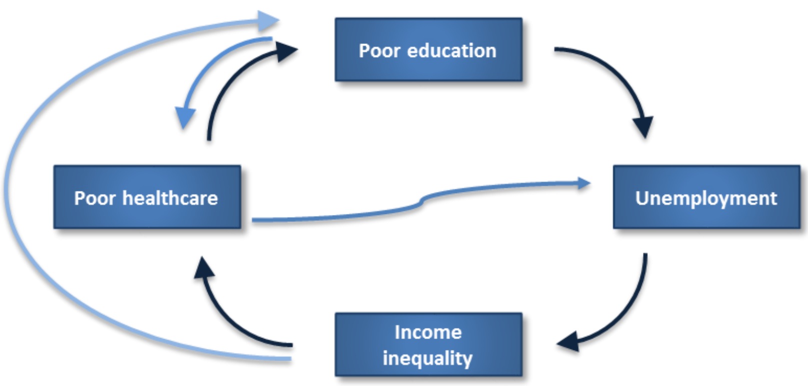


Figure 42: Poverty cycle

The primary path of the cycle can be considered to begin with poor education which results in a lack of skills and hence leads to unemployment; unemployment leads to income inequality, in some cases lack of income entirely, which leads to a lack of funds for appropriate healthcare. Parallel paths show that a lack of funds also leads to poor education not only for the current generation but also the next; poor education can also lead to poor healthcare through lack of knowledge on risks and remedies; poor healthcare can also inhibit the ability to receive education or find employment.

In Chapter 2, South Africa's competitive position in the global titanium supply chain was looked at and this forms the basis for our second area of interest. South Africa is among the world's largest producers of titanium; however, the country is lacking in downstream production on the value chain. Most the country's mined reserves are exported in the form of titanium slag with a value of approximately half a US Dollar per kilogram contained titanium; the budding titanium machining industry imports mill products whose value is almost tenfold greater per kilogram contained titanium. This equates to a sizeable missed opportunity to add value to the country's exports and highlights one of the challenges identified in developing the NDP 2030, the country's unsustainable exploitation of natural resources. In Figure 2 in Section 2, the titanium value chain was depicted; the same value chain in a South African context more closely resembles Figure 43; it is important to remember that this figure isn't meant to be an exact representation of South Africa's. Developments in titanium powder production as described in the previous section are excluded from this figure. In Chapter 2 the titanium metal market was also looked at and this also forms part of our area of interest.

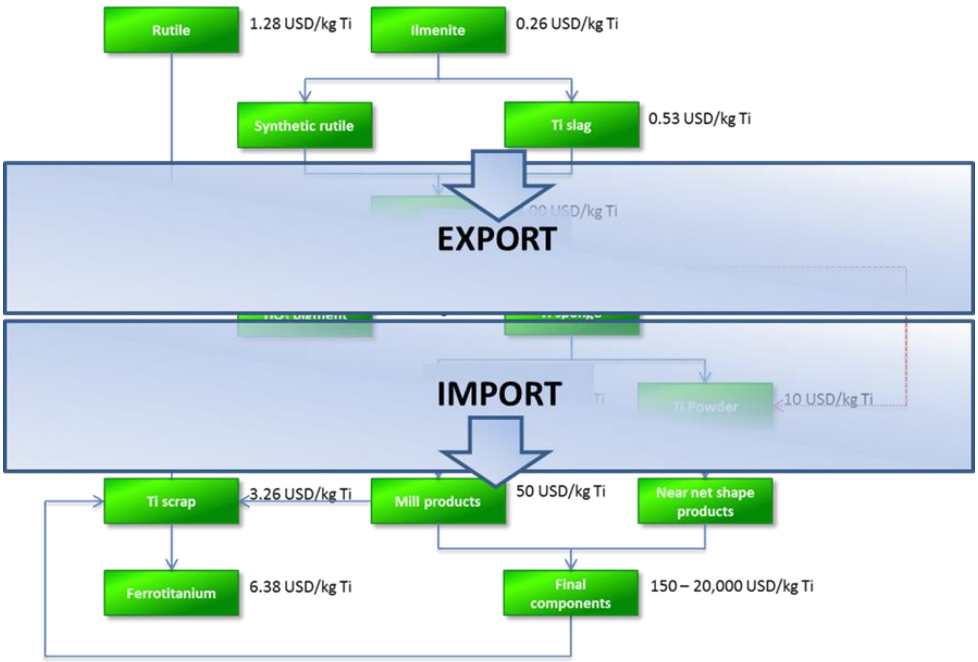


Figure 43: Illustration of South Africa's poor utilisation of the titanium value chain

To explore the links between these two areas they need to be explored in greater detail and "richness" by identifying and mapping the interactions between the following (Williams, 2005): structures, processes, climate, people, issues expressed by people, and conflicts. This is done with the use of what Checkland (1991) calls a "rich picture." As two separate areas are being dealt with, each with different themes and a significant amount of potential detail, two separate "rich pictures" are drawn up, shown in Figures 44 and 45.

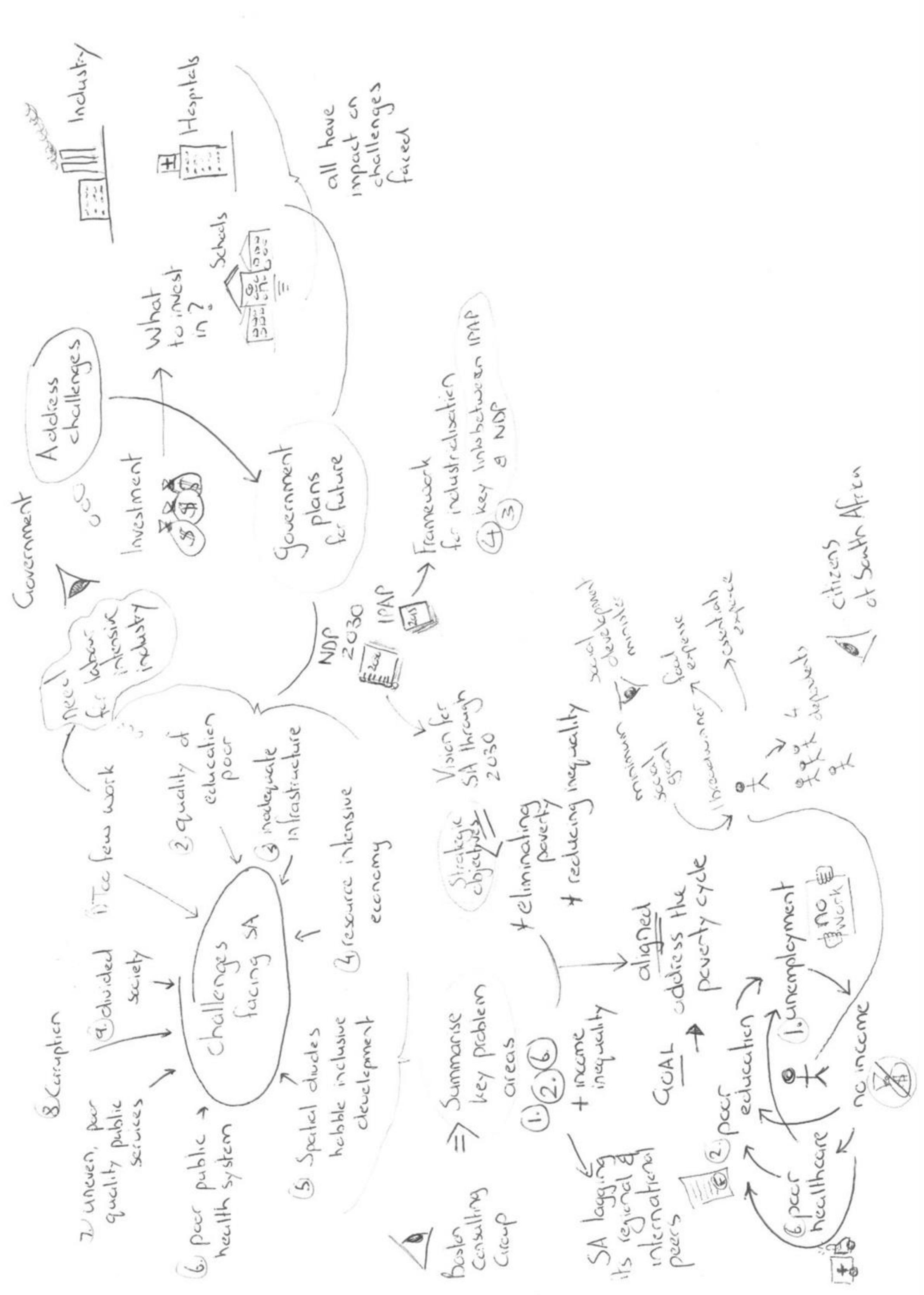


Figure 44: Rich picture depicting South Africa’s present socio-economic situation

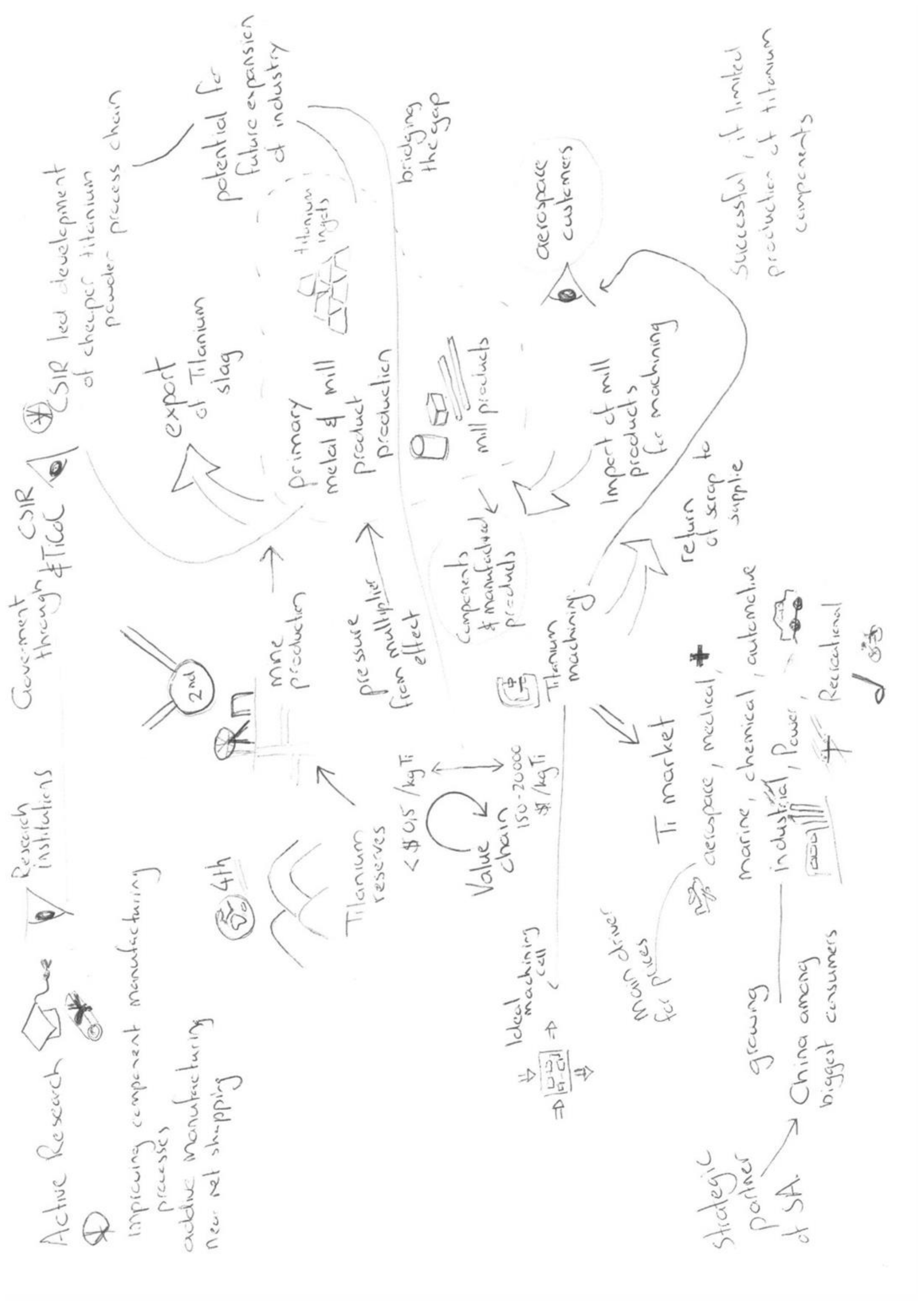


Figure 45: Rich picture depicting the titanium industry in a South African context

5.2 Determining the scale of systems of interest

Before carrying on with the soft systems analysis it is important to determine what scale of systems we are looking at.

- South Africa's present socio-economic situation
- The titanium industry in a South African context

A large portion of this thesis deals with describing South Africa's present socio-economic situation in detail, which is summarised by the rich picture in Figure 44, however even this rich picture can't cover all aspects as it involves the entire country and all economic activity. It is therefore difficult to exploring this in too much detail as the scope would be too vast. We can simplify the situation while still exploring it in sufficient detail by looking at the impact on:

- a local community,
- potential employees,
- and their dependents.

The titanium industry in a South African context has also been covered extensively in this thesis, summarised by the rich picture in Figure 45. The scope of this thesis does not cover the entire titanium industry in extensive detail, the focus is the impact of titanium machining, and therefore the rich picture needs to be explored bearing this in mind. An important point to note when considering the impact of titanium machining on society is that it is a specialist and therefore comparatively small industry so it may not have a significant direct impact on a South African scale. It will not directly create many additional jobs and only facilitate skills development in a limited capacity. Figure 46 is a simplified visualisation of the scale of a titanium machining industry and broader titanium industry in the South African economy. To look at titanium machining at the same level that South Africa's socio-economic situation is being locked at, the "ideal" titanium machining cell described in the previous chapter is used. While the impact of a single titanium machining cell on the titanium industry and on the challenges facing South Africa may be insignificant, its impact on a local community will be measurable.

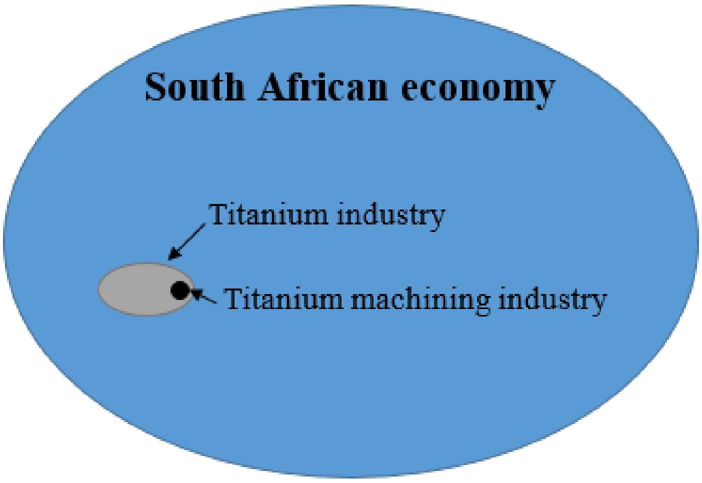


Figure 46: Visualisation of titanium machining's role in the economy

The indirect impact and multiplier effects of establishing successful titanium machining industry still need to be considered. The development of a new industry, or expansion of an existing one has an impact on both upstream and downstream industries and a direct and indirect impact on job creation. Figure 47 shows a diagram summarising the multiplier effect of a new industry or expansion of an existing industry. Following the figure the establishment of a titanium machining industry:

- can create both direct and indirect jobs,
- improve the trained labour pool,
- increase demand for services,
- grow the local population and increase the tax income,
- and lead to growth of the tertiary sector.

Most importantly, growth in the industry and the local area can lead to the attraction of linked industry, in the case of titanium machining the expansion of the broader titanium industry where the gains for the country are compounded. The TiCoC has already do work to estimate what kind of initial impact a titanium machining industry, and broader titanium industry would have in terms of job creation. The results are shown in Figure 48, taken from a presentation to the Science Councils Symposium by Dr Wille du Preez (2014). As can be seen in the figure, the machining industry stands to generate 180-220 direct jobs initially with the entire industry generating 700-950 jobs.

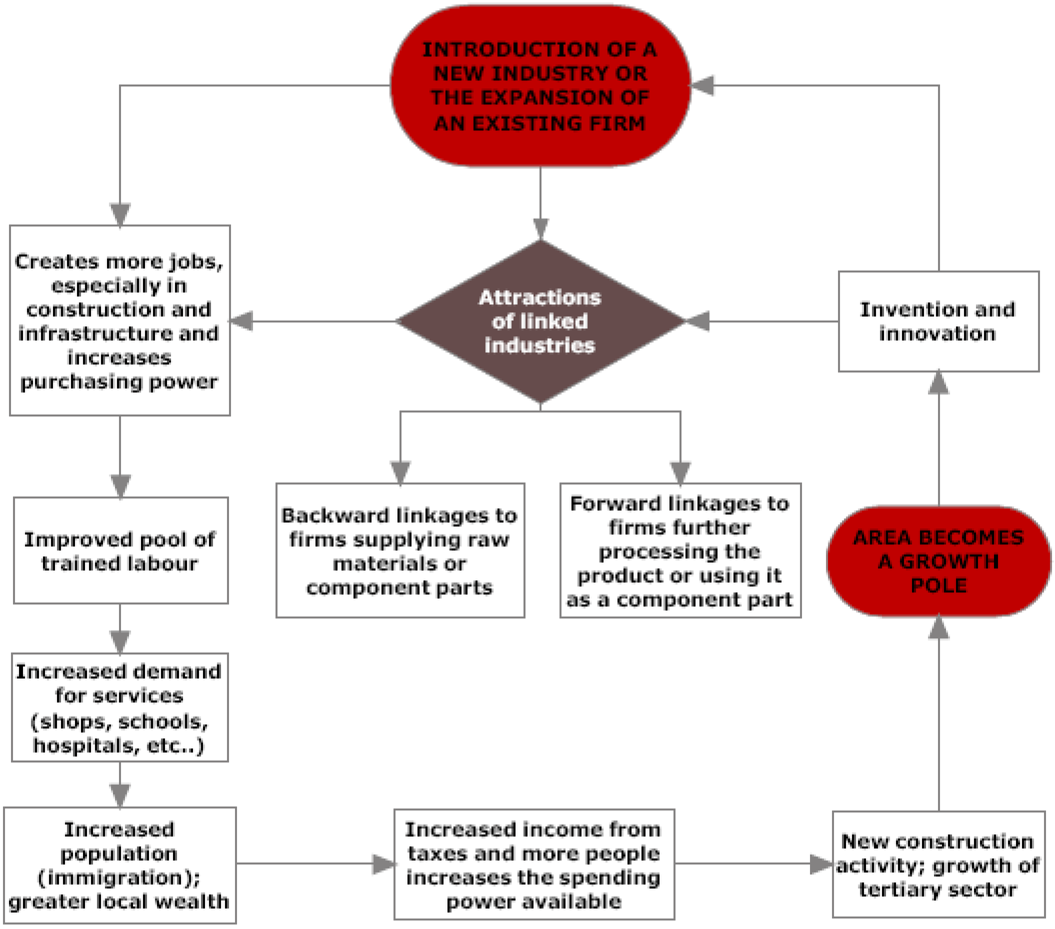


Figure 47: Visualisation of the multiplier effect (Barcelona Field Studies Centre, no date)

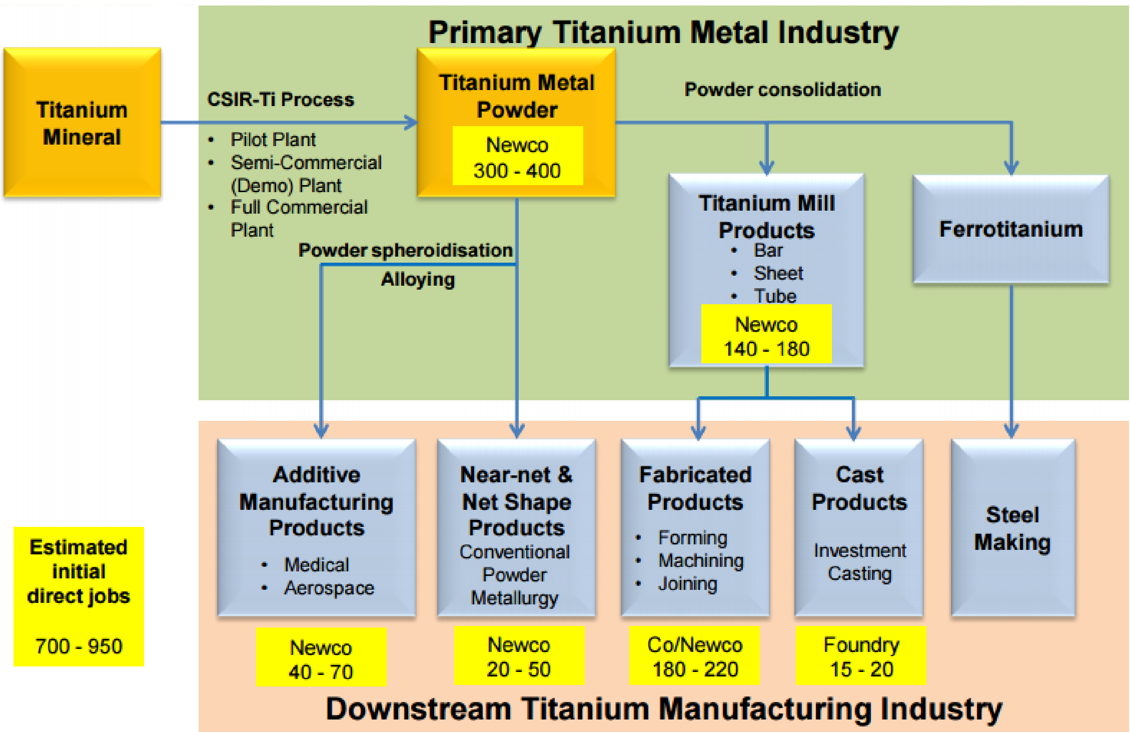


Figure 48: Initial job creation opportunities from a titanium industry (Du Preez, 2014)

5.3 Root definitions of relevant systems

The next stage of SSM involves moving into the world of systems and identifying the root definitions of different sub-systems at play. This is done by first looking at the situation from different perspectives and identifying what Checkland (1991) calls "holons" that describe real world activities. The following were identified for the two focus areas expressed in Figure 35 and Figure 36.

- Means of reducing unemployment
- Means of improving healthcare
- Means of improving education
- Means of improving infrastructure
- Means of addressing spatial divides
- Means of reducing resource dependence
- Government investment in industry
- Government investment in hospitals
- Government investment in schools
- Eliminating poverty
- Reduction of inequality
- Breaking the poverty cycle
- Dependence on social grants
- Single breadwinner supporting several dependents
- Framework for industrialisation in South Africa
- Plan for future of South Africa
- Improving the process of titanium powder production
- Entering the titanium metal market
- Capitalising on the favourable position in the titanium supply chain
- Collaborative research to improve component and product manufacture
- Use of additive manufacturing
- Use of near net shaping
- Growing titanium market sectors
- Change in price of titanium
- Manufacturing products for aerospace sector
- Beneficiation of titanium resource
- Bridging the gap between export and import of titanium in different forms

The above list is by no means a complete collection of all possible perspectives. The next step in soft systems modelling involves selecting which "holons" to take further. However, the above "holons" only deal with either area of interest as they were examined in isolation, which is not ideal. The scope of this thesis does not include solving unemployment, education or health problems; nor does it include developing process chains for titanium beneficiation or bridging the gap between South Africa's titanium exports and imports. It does however include showing how titanium machining can aid in addressing the challenges facing South Africa to show that it is an area Government should invest in. It is therefore important to look at the two "rich pictures" not in isolation, but together to determine a set of "holons" that can link them.

Therefore, the following additional holons were identified by focusing on both "rich pictures".

1. Government investment in titanium machining
2. A titanium machining cell can help combat poverty
3. Addressing the challenge of a resource intensive economy with titanium machining
4. Titanium machining can stimulate growth in the broader titanium industry

The fourth "holon" given above is defined by the multiplier effect given in Figure 47 and its outcomes will be included in the other "holons," it will therefore not be taken further.

Checkland (1991) proposes analysing the selected "holons" or perspectives using a development process abbreviated as CATWOE to determine the root definitions and define systems that carry out the processes involved. The CATWOE analysis involves the following elements as per Williams (2005):

- Customers - who gains from the transformation
- Actors - who facilitates the transformation
- Transformation - the change from start to finish
- Weltanschauung - what gives the transformation meaning
- Owner - who owns the system
- Environment - what influences the system, but does not control it

The following sections contain CATWOE analysis for the three "holons" described above. These systems can then be combined to create a conceptual model of the situation. Two important considerations need to be applied when developing our conceptual model.

1. While all "holons" are examined individually and yield individual systems, the bigger picture needs to be considered. The identified systems will need to be combined to form a cohesive whole.
2. To achieve this, it is prudent to fix a few elements of the CATWOE analysis

The aim is to derive a conceptual model that links the titanium industry and the challenges facing South Africa. Developing a model encompassing the entire titanium industry and all challenges facing the country would be too great a task and beyond the scope of this thesis. Focus is placed on a single titanium machining cell, and the impact it can have on its surroundings. Therefore the "ideal" titanium machining cell, as defined in Section 4.4, is selected as the Actor in all future CATWOE analysis. There will be exceptions to add necessary detail to the model, but these will be of an appropriate scale so that they can interact with the rest of the systems. It is also important to note that one of the objectives of this thesis is to show that Government should invest in a titanium machining industry, therefore Government will be the Owner of all systems developed. As the systems need to form a cohesive whole, it is also important to consider them within the same environment. To ensure the all subsystems can interact with one another care must be taken to ensure that they address customers and transformations at similar levels. For each of the "holons" one or more systems are identified, in these systems the following applies:

- Circular elements are activities
- Triangular activities are performance measures
- Solid connections indicate dependencies
- Dashed connections indicate influence

5.3.1 Government investment in Titanium machining

This "holon" looks at the outcomes of investment in titanium machining. Details of the iterations are given in Table 12. For the first iteration of CATOWE analysis, the titanium machining cell was looked at as the Actor, as explained previously and the local community was chosen as the customer. This didn't yield desirable results, as the "holon" deals with investment in titanium machining, the titanium machining cell needs to be considered as the customer. The second iteration yielded the following root definition:

- Government backing of a titanium machining cell will allow it to grow, yielding economic benefits.

Activities identified to carry out this transformation are as follows:

1. Increase in capital
2. Increase in capex
3. Expansion of operations

The above root definition is not entirely satisfactory as economic benefits is too general a term. To expand on the potential economic benefits, the first iteration is reconsidered. The local community was retained as the customer, the machining cell together with growth due to investment was selected as the actor and stimulation of the economy as the transformation.

In this way, the activities identified for the previous iteration can be retained and the following root definition is achieved:

- Government backing of a titanium machining industry will allow it to grow, stimulating the local economy for the benefit of the local community.

Activities to carry out the transformation are as follows, the system linking these activities to carry out the desired transformation is shown in Figure 49.

1. Increase in capital
2. Potential increase in capex
3. Expansion of operations
4. Increased availability of jobs
5. Greater ability to provide skills training
6. Increased employee skill
7. Establish local demand for mill products
8. Local economic growth (outcome)
9. Retain skills (performance measure)

Table 12: CATWOE for: Government investment in titanium machining

Iter.	Customer	Actor	Transformation	Weltanschauung	Owner	Environment
1	Local community	Titanium machining cell	Investment	Growth provides economic benefits	Government	Titanium market, pre-existing government plans and policies, social climate
2	Titanium machining cell	Investment	Growth in the industry	Growth provides economic benefits	Government	Titanium market, pre-existing government plans and policies, social climate
3	Local community	Growing titanium machining cell	Stimulation of economy	Economic growth	Government	Titanium market, pre-existing government plans and policies, social climate

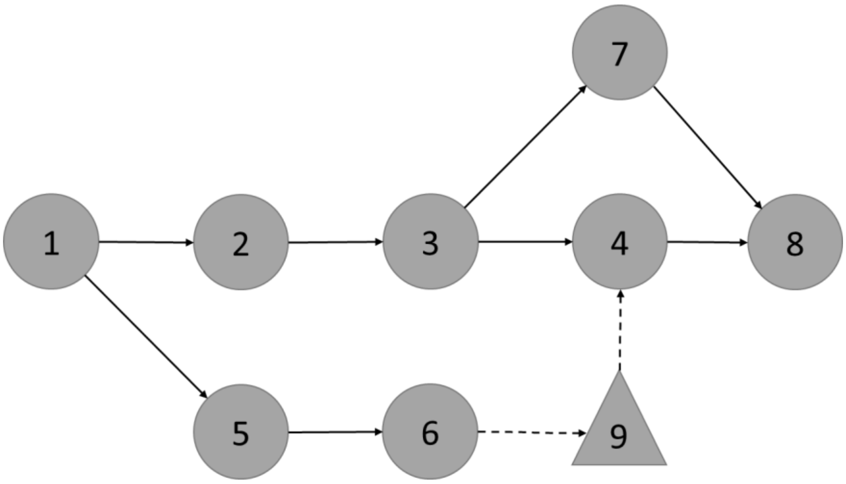


Figure 49: System of activities for – Government backing of titanium machining industry will allow it to grow, stimulating the local economy for the benefit of the local community

5.3.2 A titanium machining cell can help combat poverty

This “holon” lies at the heart of what this thesis is attempting to show, the impact titanium machining can have on the challenges facing South Africa. Therefore, multiple iterations were carried out to identify multiple root definitions to address different aspects of this “holon”. Details of the iterations are given in Table 13.

The first three iterations involved trying different customers that could benefit from the transformation of eliminating unemployment by a government backed titanium machining cell. The fourth iteration takes into consideration that eliminating unemployment is only one of the steps in the poverty cycle and it would be prudent to address the cycle directly with a root definition. Therefore, for the fourth iteration the titanium machining cell remained the actor, carrying out the action of combating the poverty cycle for the benefit of its employees and their dependents. This yielded the following root definition:

- Government backed titanium machining combats the poverty cycle, allowing employees to have an improved standard of living.

Activities to carry out the transformation are as follows, the system linking these activities to carry out the desired transformation is shown in Figure 50.

1. Create employment opportunities (outcome)
2. Provide fair and competitive benefits
3. Provide remuneration
4. Provide in-service training
5. Provide healthcare benefits
6. Increased employee

7. Improve employee health
8. Afford the ability to care for dependents
9. Improve standard of living (outcome)
10. Monitor job performance (performance measure)
11. Monitor absenteeism (performance measure)

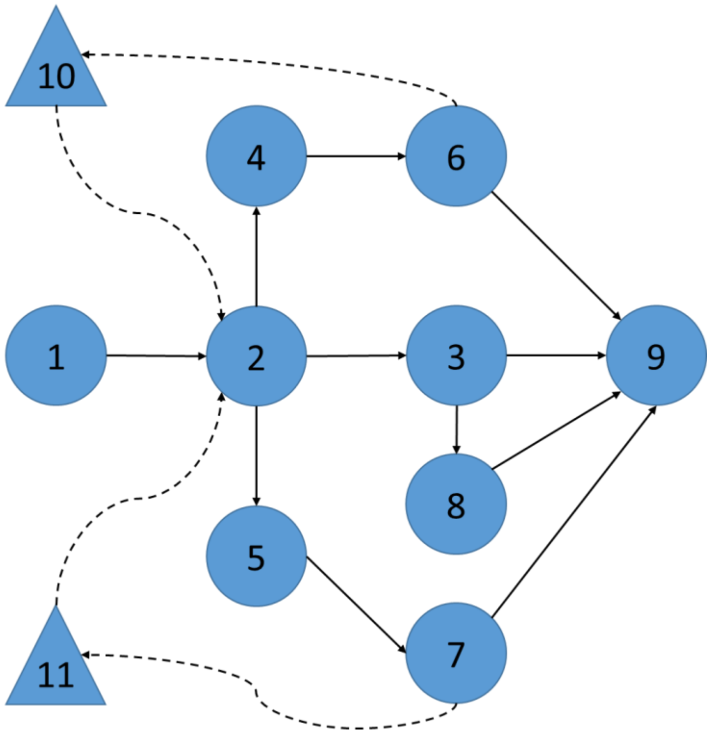


Figure 50: System of activities for – Government backing of titanium machining industry combats the poverty cycle, allowing employees to have an improved standard of living

For the fifth iteration, it was decided to look at the local community as the customer for the transformation of combatting the poverty cycle which is important so that the local economy and community can grow. However, it was decided to get a more meaningful root definition, the transformation and Weltanschauung need to be reconsidered. The sixth iteration expanded on Section 5.2.1 by taking the growing titanium machining cell as the actor, instead of taking stimulation of the economy as the transformation, economic growth itself was considered. This yielded the following root definition, closely linked with the root definition of Section 5.2.1:

- A growing titanium machining cell grows the local economy, allowing spatial divides to be addressed and increases the spending power of the local community.

Activities to carry out the transformation are as follows, the system linking these activities to carry out the desired transformation is shown in Figure 51.

1. Local economic stimulus

2. Create employment opportunities
3. Local population growth
4. Increased demand for services
5. Expansion of schooling
6. Expansion of healthcare
7. Increased tax income
8. Increased spending power
9. Ability to provide services (performance measure)

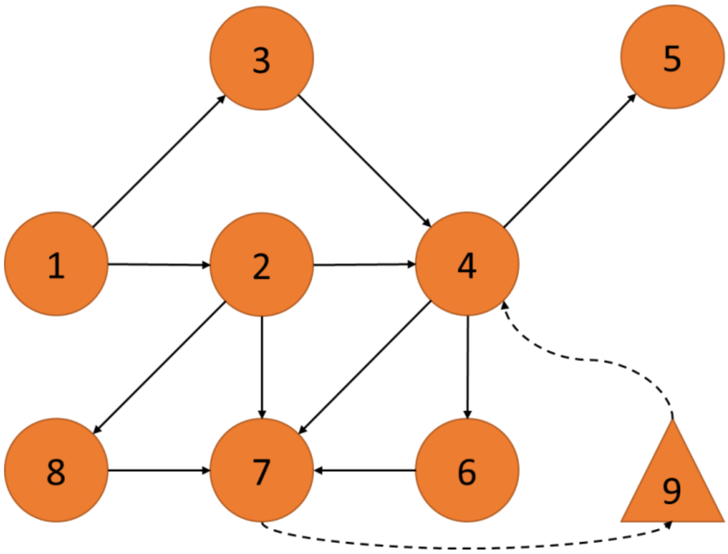


Figure 51: System of activities for – Government backing of titanium machining stimulates local economy, allowing it to grow, thereby stimulating local population growth and increasing spending power

One final iteration was carried out for this "holon" to better define the impact on the dependents of employees at the machining cell. For this reason, the employees were taken as the actor, their dependents the customer and the titanium machining cell the owner. This yielded the following root definition:

- Employees of titanium machining cell combat the poverty cycle allowing their dependents to have an improved standard of living.

Activities to carry out the transformation are as follows, the system linking these activities to carry out the desired transformation is shown in Figure 52.

1. Earn income
2. Provide education
3. Provide healthcare
4. Provide food
5. Provide necessities

6. Have money leftover
7. Save money
8. Spend on luxuries
9. Improved standard of living
10. Track income vs. expenses (performance measure)

Table 13: CATWOE for: A titanium machining cell can help combat poverty

Iter.	Customer	Actor	Transformation	Weltanschauung	Owner	Environment
1	Single employee and dependents	Titanium machining cell	Unemployment eliminated	Breaks poverty cycle	Government	Titanium market, pre-existing government plans and policies, social climate
2	Local community	Titanium machining cell	Unemployment eliminated	Breaks poverty cycle	Government	Titanium market, pre-existing government plans and policies, social climate
3	Employees and dependents	Titanium machining cell	Unemployment eliminated	Breaks poverty cycle	Government	Titanium market, pre-existing government plans and policies, social climate
4	Employees and dependents	Titanium machining cell	Combat poverty cycle	Improved standard of living	Government	Titanium market, pre-existing government plans and policies, social climate
5	Local community	Titanium machining cell	Combat poverty cycle	Improve local economy and grow community	Government	Titanium market, pre-existing government plans and policies, social climate
6	Local community	Growing titanium machining cell	Economic growth	Addresses spatial divides, improved community spending power	Government	Titanium market, pre-existing government plans and policies, social climate
7	Dependents	Employee	Combat poverty cycle	Improved standard of living	Titanium machining cell	Titanium market, pre-existing government plans and policies, social climate

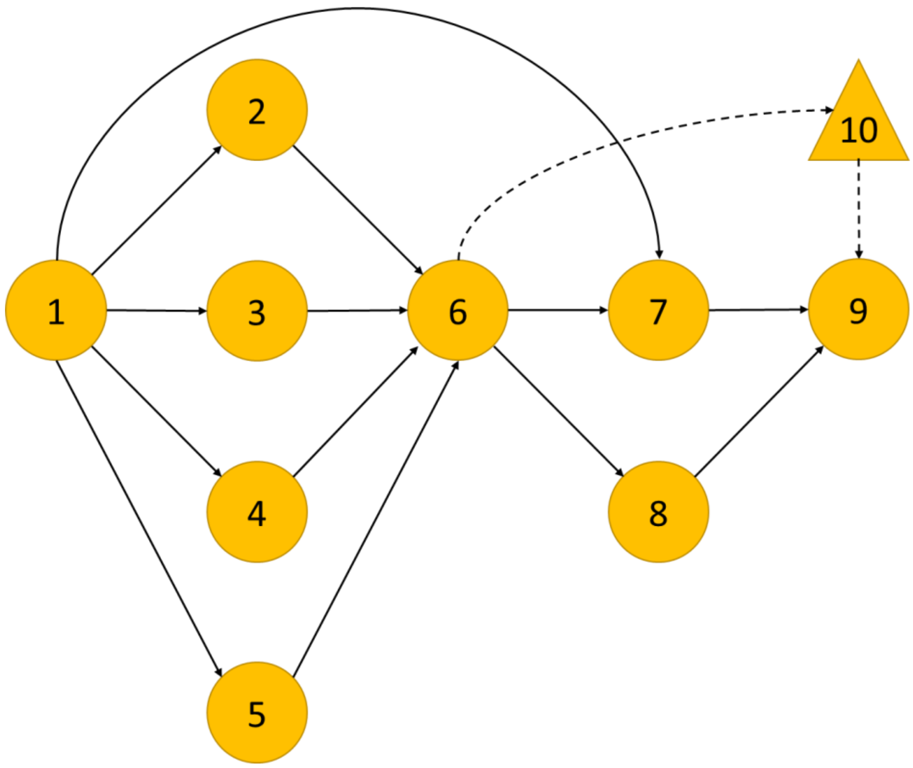


Figure 52: System of activities for – Employees of titanium machining cell combat the poverty cycle, allowing their dependents to have an improved standard of living

5.3.3 Addressing the challenge of a resource intensive economy

This "holon" deals directly with one of the challenges identified for South Africa, but as the impact of this can only be seen on a much bigger scale than we have been operating, the aim is to identify a root definition that can bridge the gap and thereby indicate the potential effects of a broader titanium machining industry. Details of the iterations are given in Table 14.

The first iteration was deemed to address the wrong situation. Natural resources were selected as the customer and through CATWOE analysis we arrived at a root definition that sought to reduce the exploitation of natural resources. While this is a valid aim, it is not one that is within the scope of this thesis. The aim we have is to reduce the economic reliance on the natural resource, meaning we want the economy to receive greater benefits from exploiting the resource than is the present case. Therefore, the second iteration sought to make primary titanium metal industries, the link between the natural resource and the titanium machining industry, as the customer and to have the transformation address growth in this industry. This yielded the following root definition, it is important to realise that this system mainly operates outside the environment of the others as it is dealing with the broader titanium industry:

- Government backed titanium machining will encourage growth in primary titanium metal industries, reducing economic reliance on titanium resource.

Activities to carry out the transformation are as follows, the system linking these activities to carry out the desired transformation is shown in Figure 53.

1. Establish local demand for mill products
2. Promote production of mill products
3. Increased local consumption of raw material
4. Reduction in raw material export
5. Reduction in mill product import
6. Improve sustainability of titanium industry (outcome)

Table 14: CATWOE for: Addressing the challenge of a resource intensive economy

Iter.	Customer	Actor	Transformation	Weltanschauung	Owner	Environment
1	Natural resources	Titanium machining cell	Reduction in reliance on natural resources	Overexploitation is not sustainable	Government	Titanium market, pre-existing government plans and policies, social climate
2	Primary titanium metal industry	Titanium machining cell	Growth in industry	Reduction in economic reliance on natural resource	Government	Titanium market, pre-existing government plans and policies, social climate

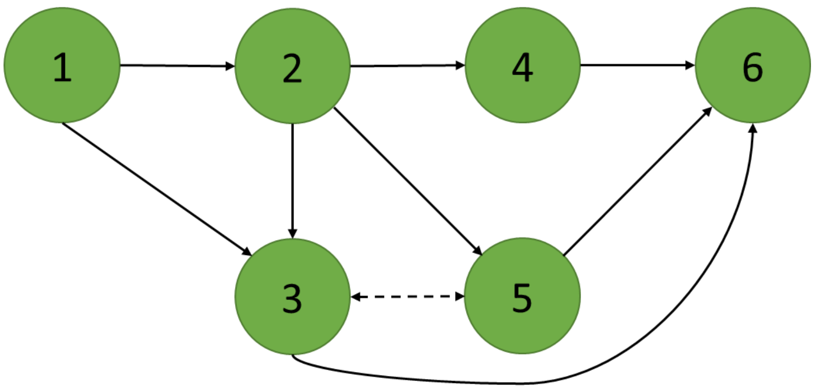


Figure 53: System of activities for – Government backed machining will encourage growth in the primary titanium metal industry, reducing economic reliance on titanium resource

5.4 Conceptual model

The previously derived root definitions and activates to carry out transformations were used to map out systems that together form a conceptual model showing the impact of a titanium machining cell, shown in Figure 54. In the figure, as with the systems in the previous section, the following applies:

- Oval elements are activities

- Triangular elements are performance measures
- Solid connections indicate dependencies
- Dashed connections indicate influence

Additionally,

- Activities and connections highlighted in red indicate links between the sub-systems

Aside from tracking progress of systems in the conceptual model using the identified measures, the performance of the model needs to be tracked against its impact on the DPME indicators identified in Section 3.3, particularly its impact on the following:

- Foreign direct investment (FDI)
- Expenditure on R&D
- SA's competitiveness outlook
- Knowledge-based economy index
- Employment
- Unemployment
- Per capita income
- Living standards measure
- Inequality measures

Using the model the impact of government investment in titanium machining can be traced yielding the following outcomes

- Creation of employment opportunities
- Improved standard of living for employees and dependents
- Improved sustainability of the titanium industry

The following benefits can also be identified as resulting from investment. Employees of a machining cell and their dependents having access to healthcare and education, and a chance to escape the poverty cycle; expansion of the local economy and with it an increased need for and ability to provide services; reducing the country's economic reliance on titanium as a natural resource.

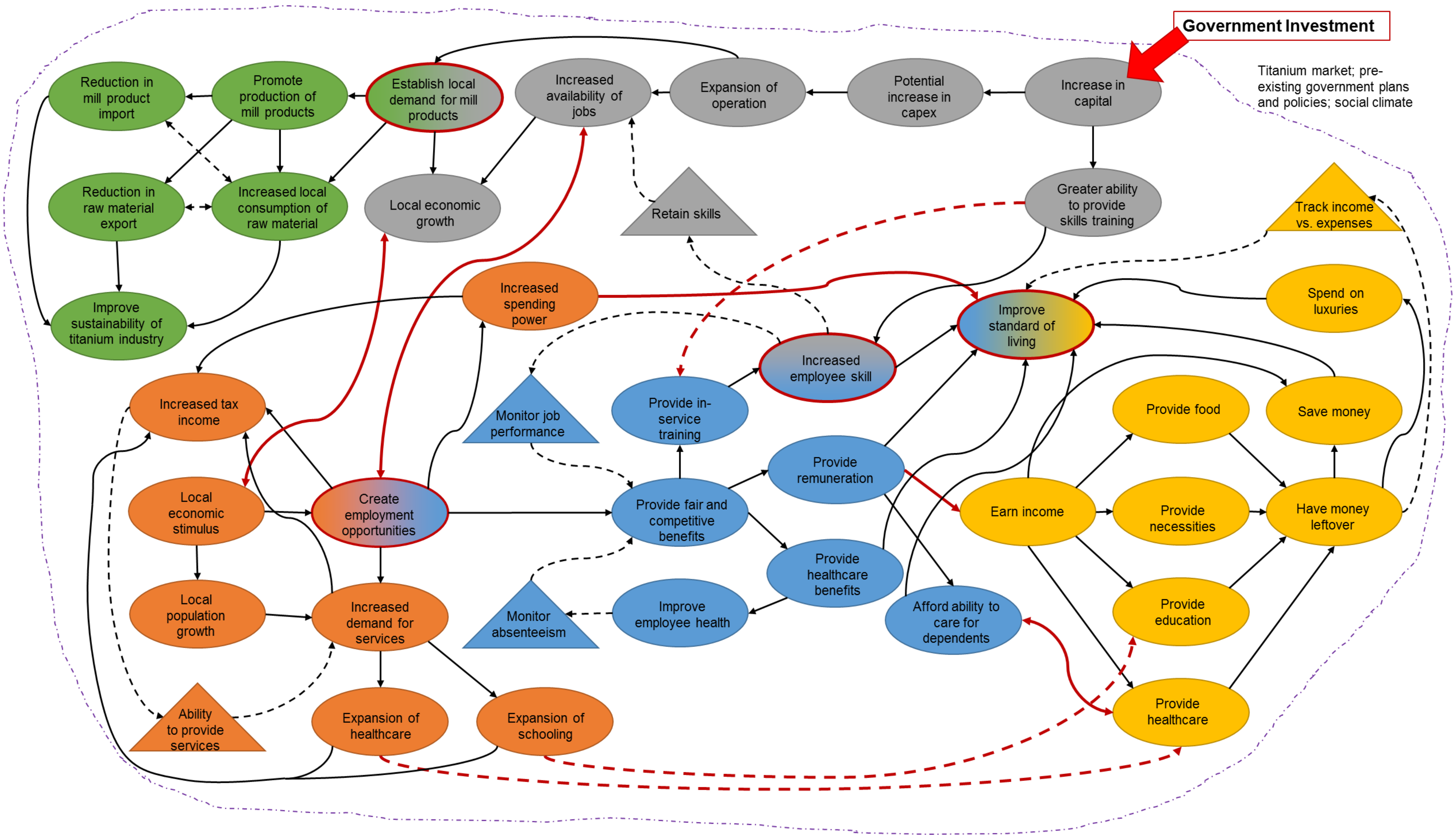


Figure 54: Conceptual soft system model showing impact of titanium machining

6. Conclusion

This study set out to explore the South African and titanium landscapes to answer the following questions:

1. Should the government invest in titanium machining?
2. Why should or shouldn't it invest?
3. What is the way forward?

It is this author's opinion after careful study of South Africa's position in the titanium supply chain and different socio-economic and techno-economic factors that the South African government should invest in titanium machining as it can address key challenges facing the country and be the driver for the establishment and expansion of a full titanium beneficiation industry and position the country as a key player in the titanium market.

6.1 Summary of results and motivations

A key point that can be identified across economic and strategic consideration, socio-economic aspects and techno-economic aspects is South Africa's present reliance on export of raw materials. The economy is built on high commodity prices driving income, which is not sustainable, especially considering commodity prices are falling. It can be understood why the economy is built this way as South Africa poses an abundance of natural resources, however change is necessary. Particularly when looking at titanium, the country holds the fourth largest reserves of titanium resource and is the world's second largest producer of titanium. Most is exported, leaving South Africa to miss out on the value add of downstream industries, which in the case of titanium are significant: From 0.53USD/kg ti for titanium slag and 3USD/kg ti for TiO_2 pigment to 50USD/kg ti for mill products and anywhere from 150 – 2000USD/kg ti for final products depending on complexity and application. Capitalising on the country's strong position in supply and expanding downstream capabilities of not only titanium, but other resources, is key to grow the economy and combat the unemployment situation facing the country.

The aerospace and biomedical sectors are strong markets for titanium mill products, particularly in the United States and Canada, and the European Union. However, China's mill product consumption is almost entirely in the industrial sector, which alone consumes more titanium mill product than other regions do in total. The Industrial sector is the largest mill product consumer globally and is expected to grow substantially by 2018.

South Africa has many challenges that need to be addressed centred around the strategic aims of reducing poverty and inequality; of these, key challenges include the unsustainably resource intensive economy, spatial divides hobbling inclusive development, high unemployment, poor education and poor healthcare, the latter three form part of the poverty cycle. A typical poor South African household consists of a single breadwinner for four other dependents. PACSA identified a minimum wage of R8000 was required to allow such a household to have enough to buy food and non-food essentials and still have money left over, however such a minimum wage is not sustainable in most sectors. Specialised sectors like titanium machining require trained artisans who can easily be remunerated at such levels and above, upstream industries feeding into titanium machining can also provide competitive remuneration.

As part of research into the techno-economic aspects a concept model for an "ideal" titanium machining cell was developed, all internal process and external influences were identified. The "ideal" machining cell model was a core component of the developed conceptual model of the impact of titanium machining, the impact on its local surroundings was modelled. Through this model the potential outcomes were identified.

- Creation of employment opportunities
- Improved standard of living for employees and dependents
- Improved sustainability of the titanium industry

Further positive impacts of the machining cell were as follows: creating provisions for improvements in education and healthcare and expansion of these services in the local community, increasing spending power of the local community and tax income for the local economy, creating a local demand for mill products and thus facilitating development of primary titanium metal industries to reduce economic reliance on titanium raw product and position the country as a significant player in the titanium value chain.

The success of this needs to be gauged against government performance indicators. Through the TiCoC it has already been determined that a titanium machining industry can initially provide up to 220 jobs and the broader industry up to 950 additional jobs. It is important to remember that each R1 unit spent investing in the manufacturing sector, which is where titanium machining falls, can translate to a 1.13 unit increase in the economy.

The five pillars of industrial development that have been committed to align well with what titanium machining and the broader titanium industry bring to the table:

1. Infrastructure-driven industrialisation
2. Resource-driven industrialisation
3. Advanced manufacturing-driven industrialisation
4. Procurement

5. Regional economic integration

Development of a titanium machining industry also aligns well with competitiveness drivers highlighted to take South Africa forward, including but not limited to:

- Cost and availability of labour and materials
- Local market attractiveness
- Economic, trade, financial and tax system
- Supplier network
- Talent-driven innovation
- Government investments in manufacturing
- Healthcare system

6.2 The way forward

The concept model of the ideal machining cell needs to be refined and quantified, and tested at an industrial partner to gauge its impact. To do this key questions need to be answered:

1. What are the start-up capital requirements?
2. What are the human capital requirements?
3. What are the infrastructure requirements?
4. What type of products will be produced?
5. Will the market for the products be local or international?
6. Will the supplier of mill products be local or international?

The soft systems model needs to be taken out of the systems world and measured in the real world. Its impact can be gauged against Government's performance indicators, particularly in terms of:

- Expenditure on R&D
- SA's competitiveness outlook
- Knowledge-based economy index
- Employment
- Unemployment
- Per capita income
- Living standards measure
- Inequality measures

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